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Synoptic climatology of Pacific surface weather types.

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Monterey, California. Naval Postgraduate School

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HAROLD A. NAGEL

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SYNOPTIC CLIMATOLOGY
OF PACIFIC SURFACE WEATHER TYPES

by

Harold A. Nagel

Lieutenant, United States Navy

Submitted in partial fulfillment of
the requirements for the degree of

MASTER OF SCIENCE
IN
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SYNOPTIC CLIMATOLOGY
OF PACIFIC SURFACE WEATHER TYPES

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This work is accepted as fulfilling
the thesis requirements for the degree of
MASTER OF SCIENCE
IN
METEOROLOGY
from the
United States Naval Postgraduate School

ABSTRACT

Recent advances in weather-type development have used the 500-mb level as a basis for typing systems. Before practical applications of these weather types can be made, particularly at the surface, additional information about the associated surface patterns is necessary. To augment recent upper air weather-type classifications with more detailed surface information, a statistical analysis is made of various surface characteristics and presented in mean-track charts, tables, graphs, and individual modal cyclone models.

The author is deeply indebted to Professor W. D. Duthie, Chairman, Department of Meteorology and Oceanography, for his helpful suggestions in the preparation of this thesis.

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1. Introduction

A major objective in the field of weather forecasting today is that of improving the accuracy of extended or long-range forecasting. Present forecasts for periods up to 48 hours, termed "short range", have been determined to be highly reliable, but extended forecasts for five-day periods or longer frequently prove to be erroneous. Several methods have been developed over the past decades; these methods are based primarily on (1) statistical analysis, (2) weather typing and analogs, and (3) physical and dynamic principles. Through the extensive efforts of Krick [9] and Elliott [2 & 3], while at California Institute of Technology, weather-type classifications were established for the North American continent.

Expanding upon Elliott's North American type classifications, Holland and Mills [7] developed a classification method for weather typing the entire Northern Hemisphere.

A potential practical application of the type-classification method came into being with the establishment of the Optimum Ship Routing Program [8]. The necessity of forecasting sea and swell conditions for determining least-time tracks depends on the ability to make an accurate weather forecast for the estimated time en route. Under present conditions the minimum-time-en-route tracks are prepared using five-day weather forecasts, and the estimated least-time track is constructed for a three-day period. In a trans-Pacific crossing, particularly with a slow vessel, the en-

[illegible]

route time may be two weeks or longer. During this time, the general weather pattern may change radically, necessitating a wide diversion of the vessel from its least-time track, thus reducing the effectiveness of the Optimum Ship Routing Program. Essentially, the ideal least-time track can only be realized if the meteorological and oceanographic factors affecting the vessel's progress can be forecast with a reasonable degree of accuracy and for the entire transit period of the vessel. Once adequate extended forecasts are achieved, the sea-state conditions can be resolved and a more reliable least-time track constructed. Recent advances in computor techniques and programming also make numerical methods a potential procedure for determining more readily-available routings.

With these applications in mind, this project was designed to expand upon the Holland and Mills Zone I [7, pp. 10-47] (Pacific) classifications, specifically the associated surface patterns, in order to develop methods for forecasting the meteorological parameters related to wave and swell forecasts.

2. Development

In 1944 Gentry [5] developed a surface (sea-level) classification system composed of four groups for the Pacific Ocean area which were determined by the stability of the frontal wave and the existence of a deep low to the north. His results included the position of the deep low, the frontal wave, and locations of the favorable areas for cyclogenesis to occur. The history of the individual storms was not evaluated, and due to the absence of 500-mb data no association with the upper-air flow was established.

A month later in the same year, Elliott [1], developed a system for classifying Pacific weather types. Again the absence of upper-air data restricted the system to surface data only. Elliott utilized the orientation and location of the subtropical highs, the trajectories of low centers, polar outbreaks, and the frontal patterns in his classification system. Noting seasonal variations, he developed 14 systems which were grouped as patterns associated with strong westerly flow, meridional flow, and Pacific complex types. Elliott's observations also indicated the existence of a storm cycle with a modal period of three days and a range of two to six days[1].

Following World War II, the interest in the upper atmosphere gave added impetus to the collection of weather data and the importance of the upper-air reference levels was soon realized. Elliott [4] made revisions to his earlier

[1]A comparison of the Elliott and Holland and Mills types is included in Appendix I.

weather types which included the 500-mb flow pattern, particularly to its steering effect on surface systems.

Utilizing seven years of data for the period 1949-1957, Holland and Mills [7] developed a weather-type classification system based on the 500-mb contour pattern for the entire Northern Hemisphere. Their system divided the hemisphere into four 90° sectors starting with the 135°E meridian. The type classifications were divided into three major categories, (1) zonal, (2) meridional, and (3) blocking, which were then subdivided into six or seven sub-types depending on the varying degree of zonal flow. However the 500-mb pattern alone does not give an adequate description of the weather conditions at the surface, particularly the surface geostrophic wind field, low-level clouds, and associated weather.

Over wide ocean expanses the absence of orographic irregularities and the relatively uniform conditions of the sea-surface temperatures are favorable for the existence of a more nearly barotropic atmosphere than over continental areas. Consequently, good correlation should result between the 500-mb pattern and that at the surface, particularly in the steering influence that the 500-mb flow exerts on the surface cyclones. It has also been generally observed that the Gulf of Alaska is a region of predominantly cold dynamic lows, and most cyclones that have their origin in the western and mid-Pacific Ocean eventually terminate in the Gulf of Alaska low. However, the 500-mb pattern does not

offer an accurate indication of the surface pattern intensity.

With the 500-mb surface relationships in mind, the surface patterns corresponding to the Holland and Mills weather types were analyzed with the objective of augmenting their classification system with more complete information of the associated surface picture. Surface-data analysis was limited to the Pacific Ocean area, corresponding to the Holland and Mills Zone I sector and to the winter months, December, January, and February, primarily because of the higher frequency of storms during the winter season and for potential use in the Northern Pacific area ship-routing program.

Initial efforts were directed at obtaining mean charts of the surface isobaric field of the Pacific Area Zone I for the first, second, and third days of the chronological sequence of each type. However, it was soon noted that this would result in a seasonal mean pattern of the surface pressure which would not give an indication of the geostrophic wind field for a time interval of practical value for wave forecasting. This was obviously due to the varied position of the low centers on different charts.

A more feasible approach that served as the basic analysis of this paper was the construction of modal cyclone models for different sequences in the history of a particular cyclone. In addition to the cyclone models, storm tracks and central-pressure change were analyzed for modal, limit, and range values. The orientation and innermost closed

isobar, hereafter referred to as central isobar, of dynamic* high systems and frontal systems were evaluated subjectively.

* Dynamic refers to a pressure system associated with closed isobars through-out the troposphere.

3. Procedure

For the same history series of weather charts that Holland and Mills used in the development of their type classifications, grid values for a 30° latitude x 30° longitude area centered on the individual cyclones were recorded for the cyclone sequences. The data were grouped according to type and chronological order of the cyclone history. The first day of the cyclone life was evaluated as the first day that a closed isobar around a surface low east of 125°E longitude appeared. Normally the first day was preceded by a perceptible depression center frequently associated with a small perturbation in the quasi-stationary wave existing southeast of Japan. Once the grid values were accumulated for each type and sequence, the values at each grid point were inspected for the modal pressure gradient, radially from the center. The range of values and the percentage or frequency for the observed sample within 25% of the mode were also recorded. The modal pressure-gradient values were then plotted on a Northern Hemispheric Series Chart and cyclone models constructed, the function of the cyclone models being to indicate the orientation of the isobaric field, frontal patterns, and the pressure gradient. From the pressure gradient and isobaric orientation, the geostrophic-wind force and direction and the fetch length for determining the wave height and characteristics may be determined. The range and 25% limits are included to give an indication of the deviation from the mode and an indication of the

[illegible]

reliability of the modal value.

The 25% limit was selected arbitrarily with its basis being the 25% verification limits presently employed in evaluating grid and spot forecasts at the U. S. Naval Post-graduate School. The pressure gradients exhibited in the comparison table of pressure differences (Appendix IV) and in the histograms (Appendix V) were evaluated for a line extending due south from the center. This value was selected since horizontal length units were equal to exactly 5°, 10°, and 15° increments of latitude from the center, and the south semi-circle was considered of greater practical importance to the forecaster than the semi-circle north of the cyclone center.

To evaluate the movement and deepening of the cyclone center, the tracks of individual cyclones were grouped by type and plotted on the same scale as the Northern Hemisphere Series Charts. The movement was evaluated in degrees of latitude per day. The modal direction was observed subjectively and the number of tracks that deviated, for any 24-hour period, greater than 30° from the modal direction was recorded and indicated as a percentage of the total tracks observed. Central-isobar pressure values were recorded for successive days in the history of the cyclone. By observing the sequence of pressure changes, central-isobar tendencies were recorded and a trend chart constructed (Fig. 8 and Appendix III).

The Siberian, subtropical, and other blocking highs,

[illegible]

[illegible]

[illegible]

such as the Alaskan block were evaluated for central isobar, latitude position of the center, and orientation of the high cell's longitudinal axis or indications of meridional ridging. The relative longitude position was determined by zone. Only Siberian highs with centers east of 100°E longitude were evaluated. The maritime subtropical highs of the Pacific indicated a persistent division into east and west lobes, the west sector extending from 150° E to 160°W and the east sector from 160°W to 125°W.

Fronts were constructed on the hemispheric series charts and evaluated by a method similar to that for the direction of cyclone trajectories. The construction of the modal cyclone models (Appendix VI) required slight synoptic smoothing of the grid pressure-gradient values and the frontal lines to produce a consistent pattern.

Data were collected for the Kona-type lows, associated with blocking systems, that formed to the northwest of the Hawaiian Islands. However, an attempt at evaluating these lows indicated a wide deviation and no definite mode, so this information is only included subjectively.

4. Description of Types

The types described in this section were limited in number by the sample size for the Holland and Mills types. Sufficient data were available for evaluating two sub-types in each of the three categories, zonal, meridional, and blocking, so that a comparison could be made between types and sub-types and differences in the observed parameters noted. In selecting the types to be analyzed it was noted that during the winter season certain types were non-existent, thus indicating the effects of seasonal changes. The following types were observed to occur with the greatest frequency, and subsequently were the types used in this analysis. The types analyzed and number of days the type persisted during the three-month period for Zone I is as follows:

TYPE		FREQUENCY (Days)	OBSERVED CYCLONE SYSTEMS
Zonal;	Z-1	106	19
	Z-4	45	15
Blocking;	B-2	82	32
	B-4	77	27
Meridional;	R-5	48	15
	R-6	45	6

The frequency of occurrence is not indicative of the sample size used for this research, since the types were not evaluated if they did not persist for three consecutive days. The sample size varied not only between types but also during the five-day sequence. Frequently the number of observations

decreased from 20 for the first day to 6 and even 1 for the fifth day.

The remainder of this section describes the characteristics of the individual type patterns.

Type Z-1 Surface Characteristics

The Z-1 type surface patterns are characterized by a broad-scale zonal flow, with the modal cyclone track originating south of Japan, crossing the 180° meridian at 43°N latitude and terminating in the Gulf of Alaska. The speed of advance along this trajectory is approximately 16° latitude per day. The Z-1 lows were noticed to be split into two groups, one group originating south of 43°N latitude, which was associated with the East Asiatic-Coast cyclogenesis types II and III [6, pp. 6-15], the type III lows first being noticed as a perturbation of the quasi-stationary wave to the south of the Japanese Islands. The type II cyclones first appeared in the Sea of Japan and either curved northward and passed between Honshu and Hokkaido or filled, with new cyclogenesis occurring about 300 to 500 miles east of Japan. Of 18 observed tracks, two deviated more than 30° from the modal direction of which one curved northward abruptly and terminated near the Kamchatka Peninsula and the other curved in an anticyclonic trajectory toward the southeast. The second group of lows observed north of 43°N frequently appeared in the vicinity of the Sea of Okhotsk and were of Arctic origin. Of six observed trajectories, five terminated in the Bering Sea near the Alaskan coast, and one veered anticyclonically to the south and eventually terminated in the Gulf of Alaska. The modal value of the central isobar for the first day was 1015 mb and during the five-day history indicated the greatest deepening of any of the six types observed.

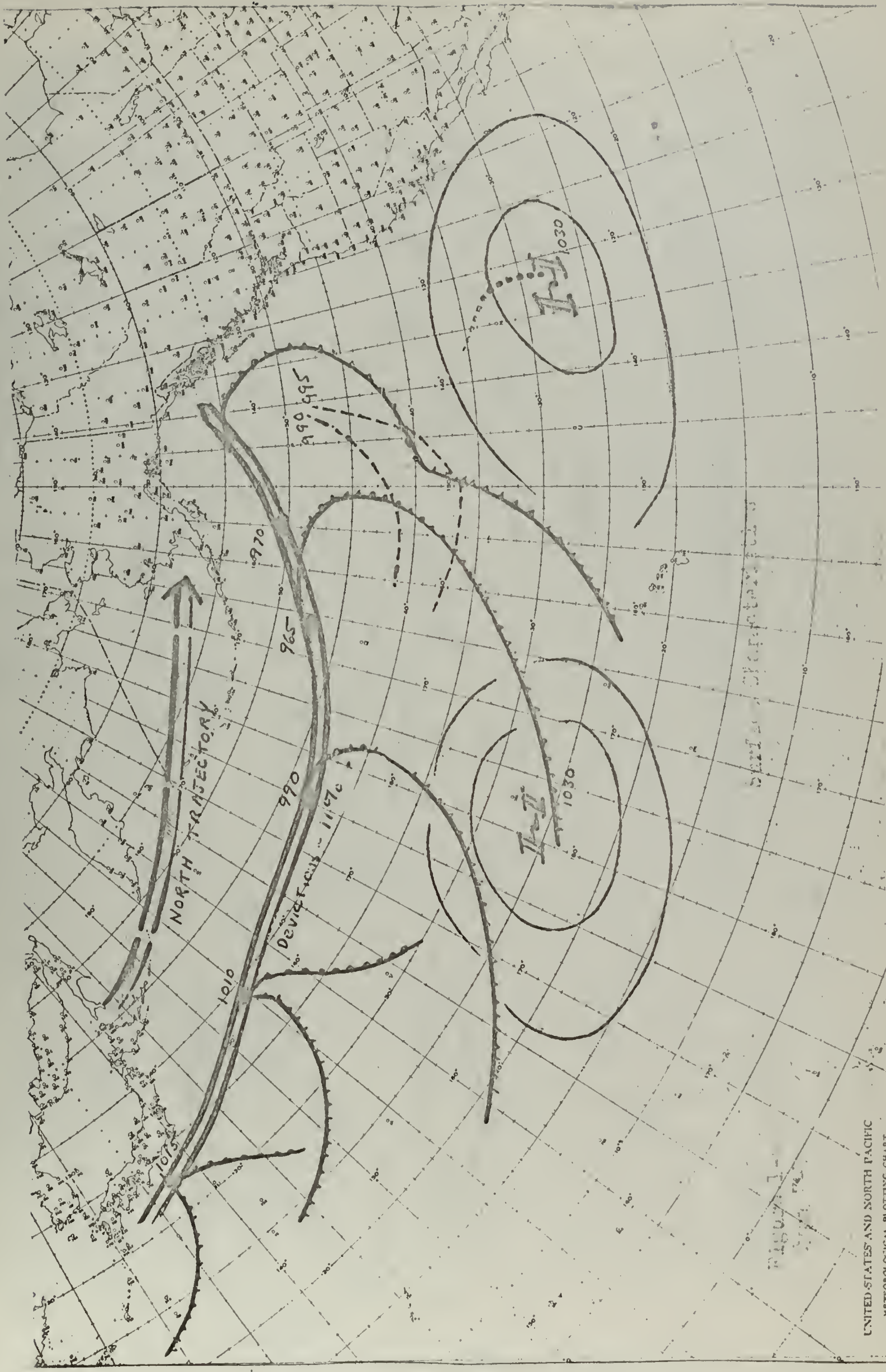
The Z-1 type also had the greatest intensity, with the pressure gradient reaching a maximum value on the fourth day.

Frequently a long frontal wave was observed to extend from the Aleutian low and trail in a southwesterly direction toward the Hawaiian Islands. Generally a small low system appeared as a perturbation of this frontal system, which was imbedded in the strong westerly-flow belt between the subtropical high and the Aleutian low to the north. Because of the complexity of these patterns and relatively small number of occurrences these systems were not included in the modal cyclone model.

The central isobar of the Siberian high for the first day of this type was 1035 mb and varied irregularly over the duration of the type, reaching a maximum modal value of 1045 mb. The Pacific subtropical high was observed as two large elongated cells with a pronounced east-west elongation of the cells. The central isobar was 1030 mb and indicated little variation over a four-day period. The latitude position of the center was noted first at 35°N latitude and progressed southward to a latitude position of 28°N by the fourth day.

By the third day the cyclone could be identified with a well-developed occluded front with the warm-sector peak about 12° latitude south of the center. Fig. 1-a displays the mean cyclone trajectory and indicates the daily movement and frontal development. The Siberian high is displayed for the first day of the sequence and the East Pacific high cell for the

fourth day. Fig. 1-b is an analyzed chart from the historical weather series and is representative of a Z-1 type surface pattern.


NORTH TRAJECTORY
1030
1030
990
970
965
990
1010
1015
UNITED STATES AND NORTH PACIFIC
METEOROLOGICAL PLOTTING CHART

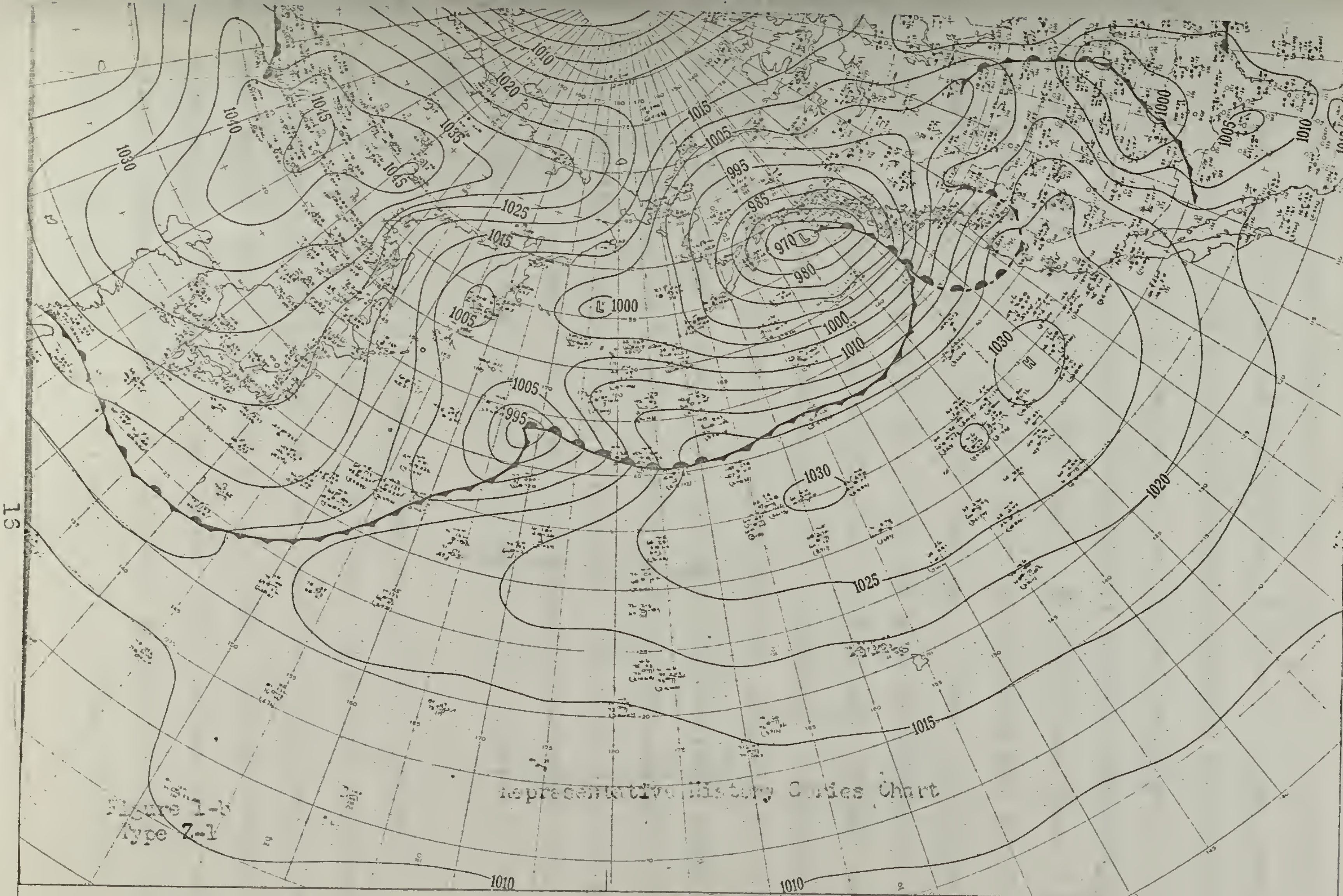


Figure 1-8
Type 7-1

Representative History [illegible] Chart

Type Z-4 Surface Characteristics

Although the frequency of occurrence of Z-4 types was considerably less than that of the Z-1 type, the comparative sample size for the Z-4 was higher, indicating the possibility of a shorter cycle or period between cyclones for the Z-4 type. (This feature was not actually evaluated as a factor.) The direction of cyclone trajectories closely paralleled those of the Z-1 type. The ratio of deviations from the mean track was higher for the Z-4 type, being four out of fifteen observations. Three cyclones assumed a large meridional component after the second or third day and terminated in the vicinity of the Aleutian Islands. The fourth cyclone appeared near the Kamchatka Peninsula with a southeast trajectory. The Z-4 average speed of advance was 11° latitude per day, which is notably slower than the Z-4 type average speed. The central isobar as observed for the first day and the deepening for the first 24-hour period were the same as that of the Z-1 type. However, the rate of deepening decreased after the second day and the systems started to fill after the fourth day.

The Siberian high was observed to have a central-isobar tendency of 1030 mb the first day of the type which increased to 1050 mb during the first four-day period, somewhat higher than the observed Z-1 type. The two Pacific subtropical high cells also appear with the Z-4 type. The average central pressure of the West Pacific high cell is 1020 mb and is highly persistent. The initial latitude

[illegible]

[illegible]

[illegible]

position is at 30°N and shifts southward to 25°N by the fourth day. The East Pacific high cell had a persistent central isobar of 1025 mb and had a mean latitude position of 32°N, with little daily variation during the four-day period. The East Pacific high cell displayed a predominant SW-NE orientation of its major axis, which was more meridional than the Z-1 type. Generally, the Western Pacific high was nearly the same for both types.

The frontal wave of the Z-4 type was similar to that of the Z-1 type for the first two days. However, the warm-sector peak of the Z-4 type for the third day was still near the cyclone center. On the fourth day, the system indicates a well developed occlusion, with the warm-sector peak at the surface located 6° to 8° latitude south of the storm center.

Fig. 2-a shows the cyclone trajectories, highs, and frontal wave patterns for the Z-4 type surface patterns. Fig. 2-b is a representative chart of the Z-4 type.

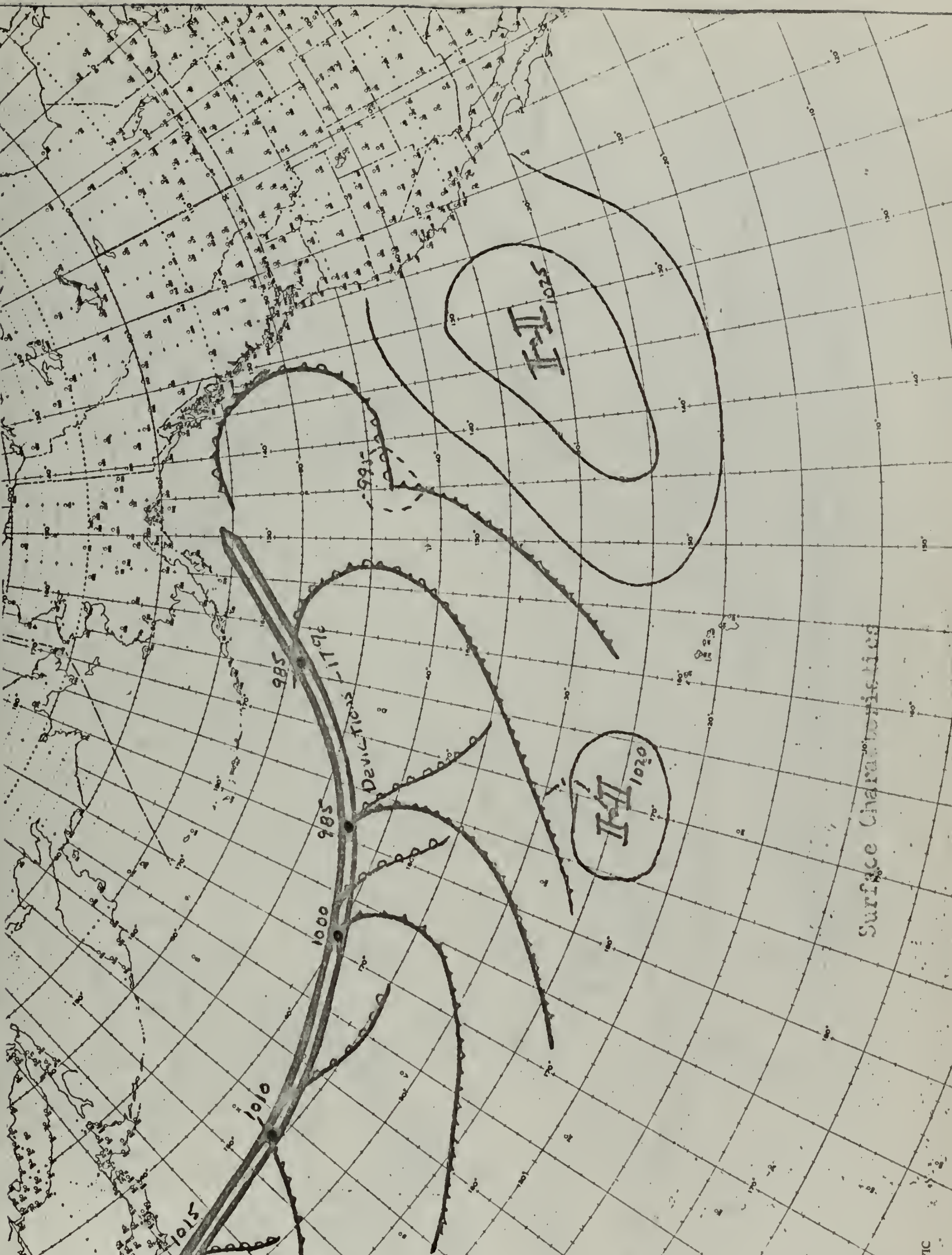


Figure 2-a
Type 2-4
Surface Characteristics

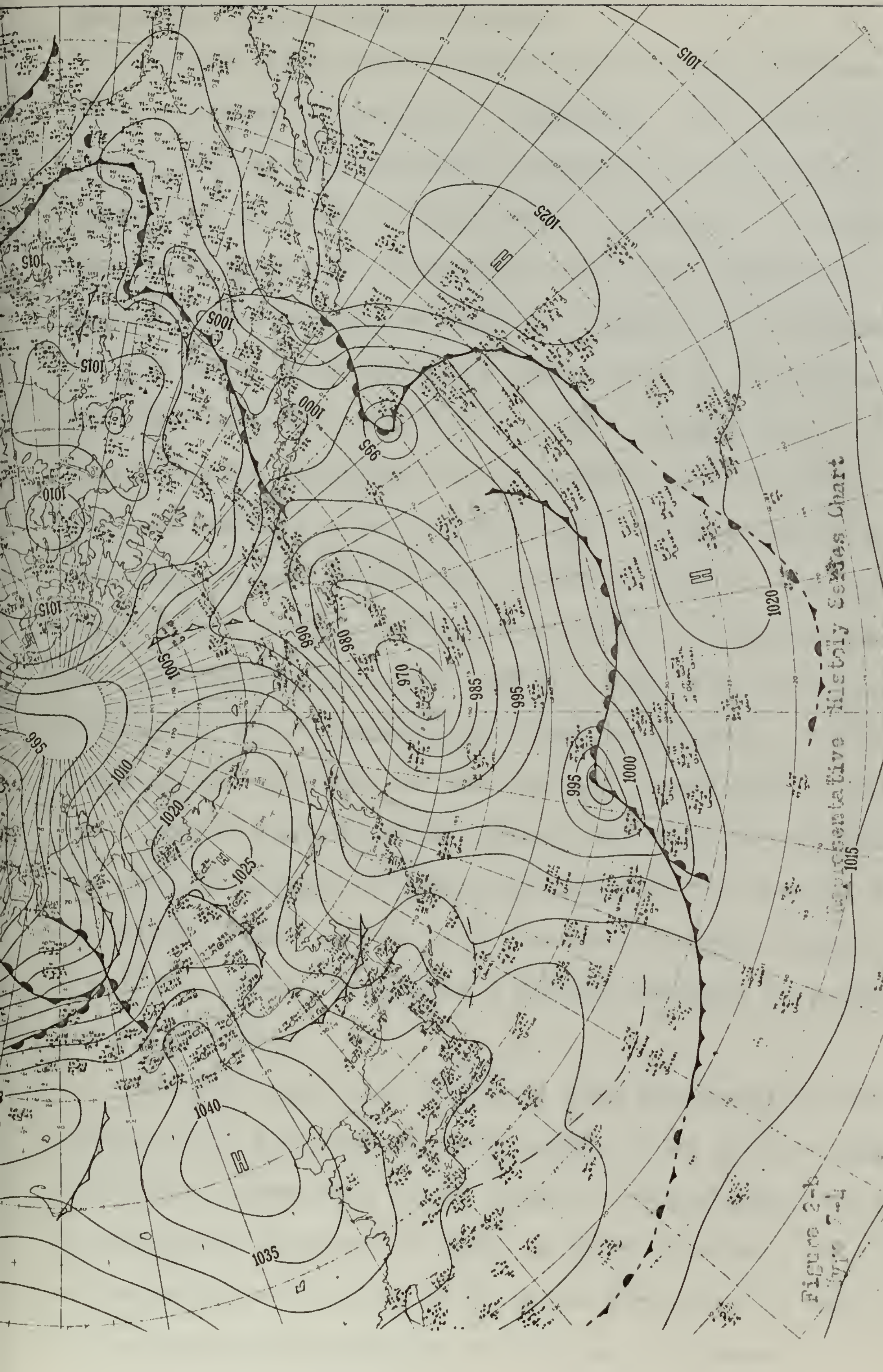


Figure 2-8
Representative History Series Chart

Type R-5 Surface Characteristics

Of the three major classifications the meridional types had the lowest frequency of occurrence. The mean cyclone tracks for the R-5 type were observed to follow a trajectory similar to that of the zonal-type cyclones out to 165°E longitude, where a perceptible meridional trajectory became evident. The R-5 trajectory was observed to be displaced farther north than the zonal types by 5° to 7° latitude. At the 180th meridian 17 of 18 R-5 type trajectories crossed north of 45°N latitude and terminated in the vicinity of the Aleutian Islands or the Bering Sea, whereas nearly all of the zonal types passed south of 45° latitude. The speed of advance for the R-5 lows along this trajectory was 18° latitude per day for the first day and decreased to 8° latitude per day as the cyclone track curved northward. The initial pressure was observed as 1010 mb and decreased at the rate of 10 mb per day for three days before filling commenced. The pressure-gradient intensity observed for the R-5 types was almost identical to that for the Z-1 type, except that the R-5 cyclones indicated a marked decrease in intensity the fourth day.

The R-5 types also differed from the zonal in the existence of a region of cyclogenesis east of the 180th meridian. There were eight cases of cyclogenesis west of the Hawaiian Islands and north of 30°N latitude. The cyclone trajectories were noted to be quite irregular in their path, but eventually terminated in the Gulf of Alaska.

The Siberian high systems observed during the R-5 type phases were quite variable in position and central-isobar value, but indicated a rising pressure trend. The Pacific western lobe of the subtropical anticyclone system was less evident for the R-5 type systems than the zonal types. When present, the central isobar was 1020 mb and located at 28°N. Frequently a meridional ridge was observed projecting northward from the high center. The Eastern Pacific high was very persistent in central isobar and latitude position of 1030 mb at 37°N. The orientation of the longitudinal axis was generally from SSW to NNE and frequently a lobe was observed extending into the west coast of North America.

The R-5 fronts indicated the development of an occlusion the second day, and by the third day a well-developed occluded front extended 8° of latitude to the SSE from the cyclone center.

Fig. 3-a illustrates the R-5 type surface characteristics and fig. 3-b is a representative chart from the history series of maps.

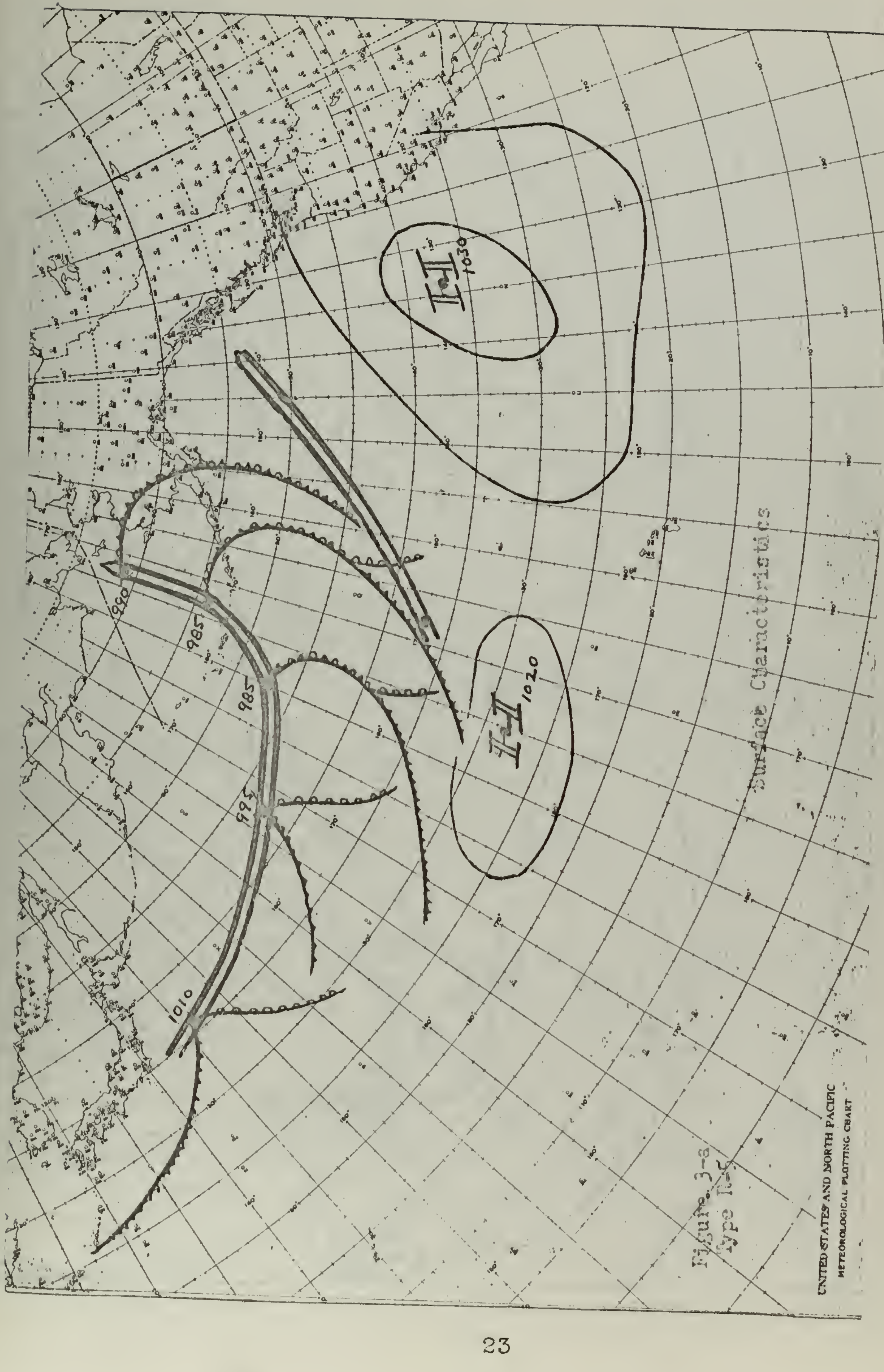
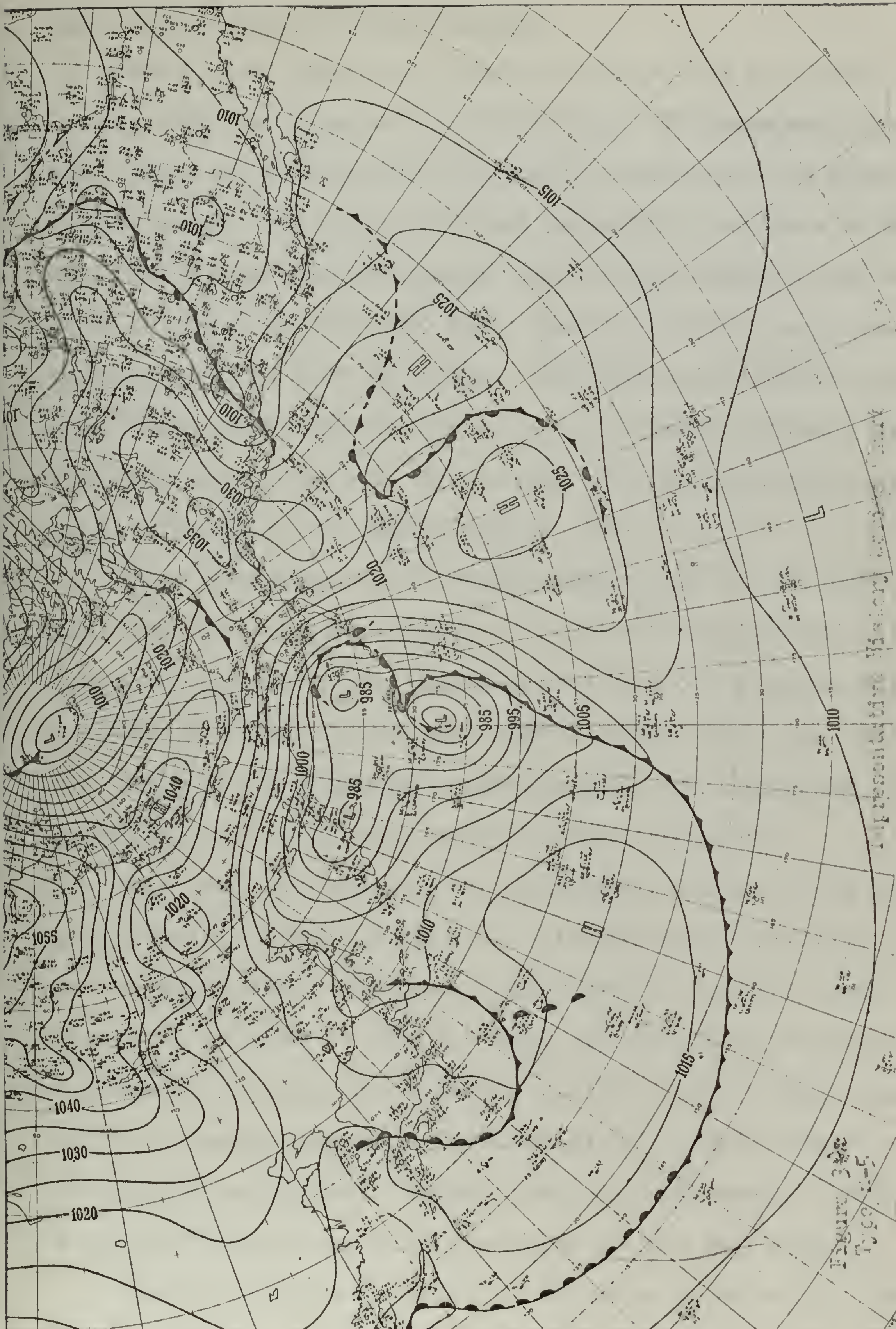


Figure 3-a
Type N-5
Surface Characteristics


1010
1015
1025
1030
1035
1020
1040
985
995
1005
1000
1055

Type R-6 Surface Characteristics

Only eight type R-6 cyclone systems were available for observation as compared to twelve type R-5 systems. The R-6 type lows appeared in the same general area as those of the R-5 type. However, the R-6 trajectory was more zonal. The individual cyclone tracks indicated a greater deviation from the mean track, with 50% crossing the 180° meridian between 40° and 45°N latitude. Two tracks followed a more meridional path passing close to the Japanese Islands and parallel to the coast. The larger observed deviation may be attributed to the small sample size.

Five observations of cyclogenesis east of the 180° meridian were characteristic of the meridional-type patterns, however. The mean longitudinal position of cyclogenesis occurred at 155°W longitude, 15° farther east than that of the R-5 type, and followed a path towards the northeast, with a modal speed of advance of 9° latitude per day.

The lows originating in the eastern Pacific indicated small variable changes in the central-isobar trend and could not be evaluated. The deepening trend of the R-6 type was identical to that of the R-5 type for the first three days, followed by continued deepening similar to the zonal types but to a lesser degree. The intensity, as determined by the pressure-gradient observations, was observed to average 3 mb per 5° latitude less than that of the R-5 type.

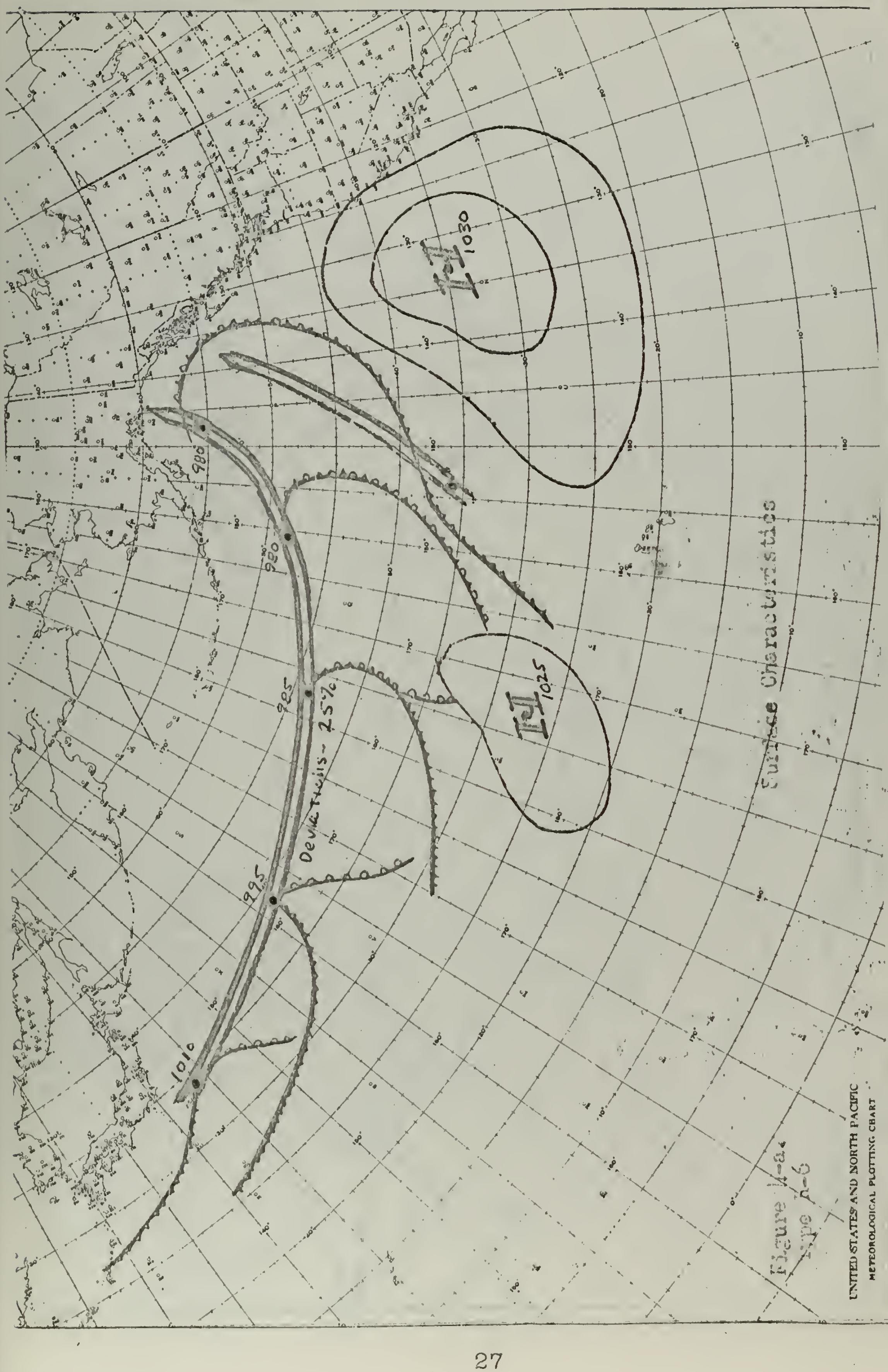
Little difference could be detected between the R-5 and R-6 type frontal patterns. The R-6 type indicated a well-

[illegible]

developed occlusion by the third day, with a meridional extent of 4° to 9° of latitude.

The western lobe of the Pacific subtropical belt was centered at a modal latitude position of 27°N latitude with a meridional ridge less developed than that of the R-5 type ridge. The eastern Pacific lobe was displaced farther eastward than that of the R-5 type with central area high pressure frequently occurring over the North American continent. The central pressure values for the R-6 type eastern-lobe highs were generally 5 mb less than those of the R-5 type.

Fig. 4-a illustrates the R-6 type surface characteristics and fig. 4-b is an example chart from the history series maps.



980
980
985
995
1010
Devel Thesis ~ 25%
1030
1025
Surface Characteristics
Figure 4-a4
Type A-6
UNITED STATES AND NORTH PACIFIC
METEOROLOGICAL PLOTTING CHART

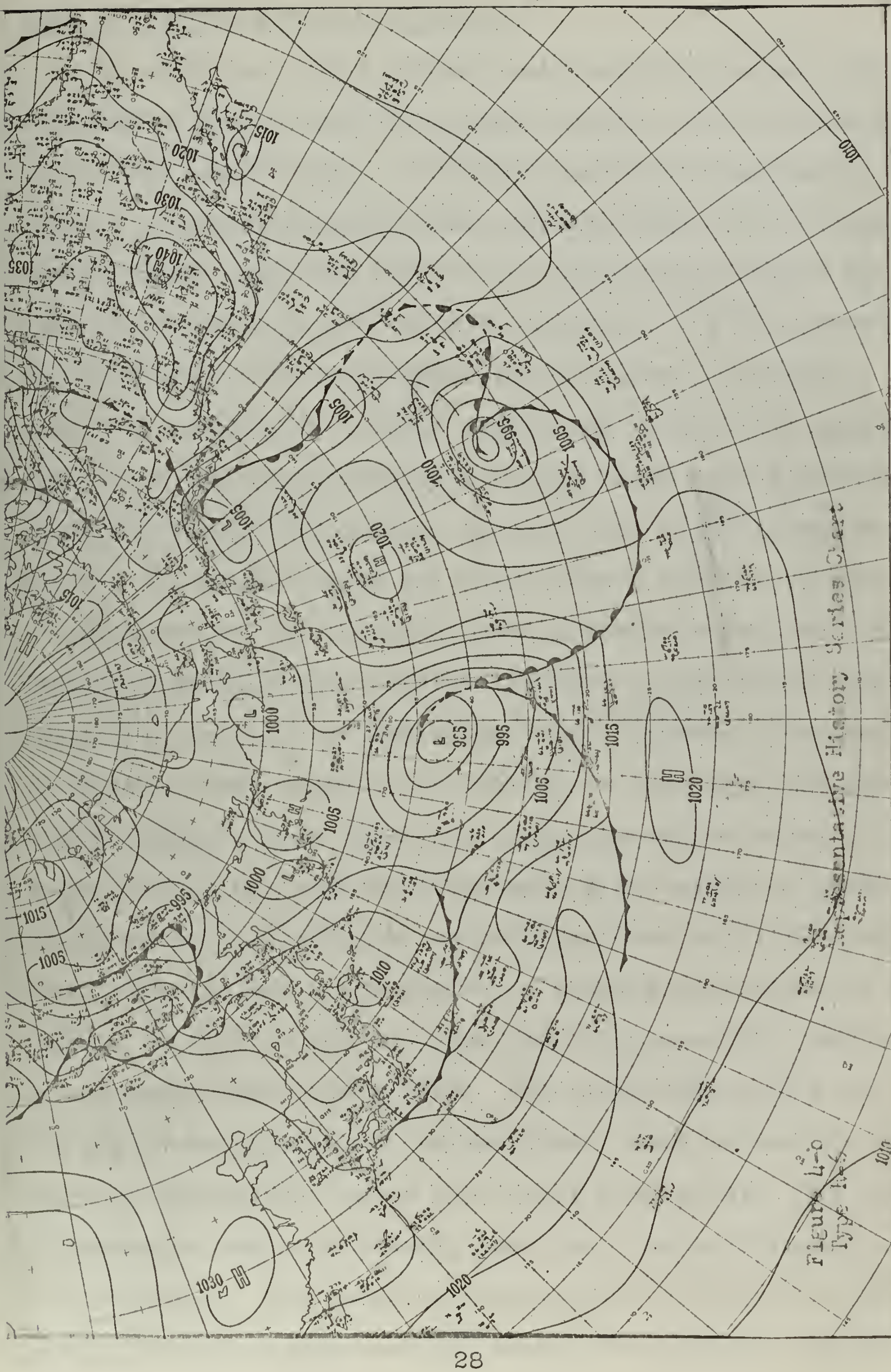


Figure 4-6 Representative History Series Chart
Type N

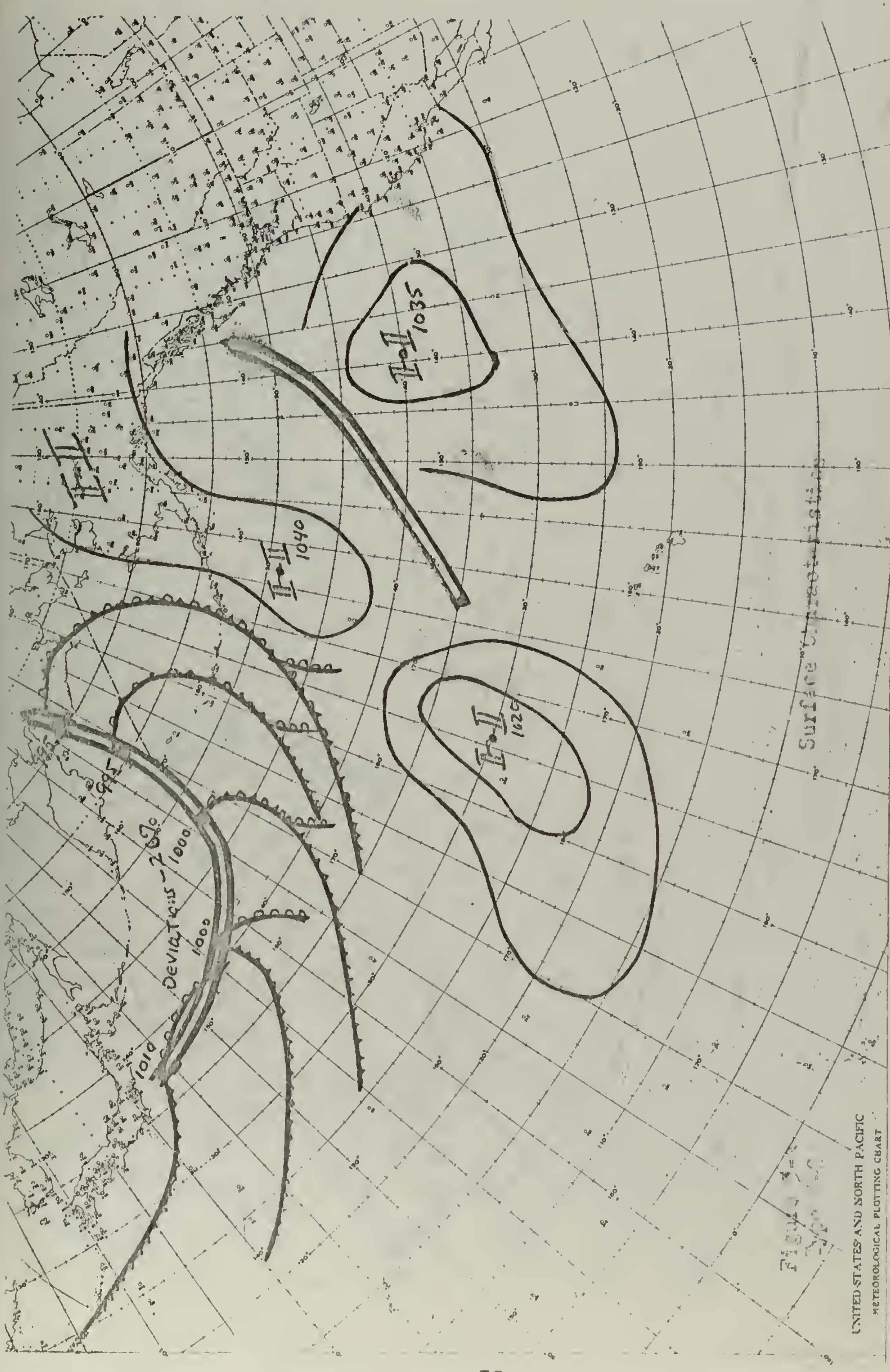
Type B-2 Surface Characteristics

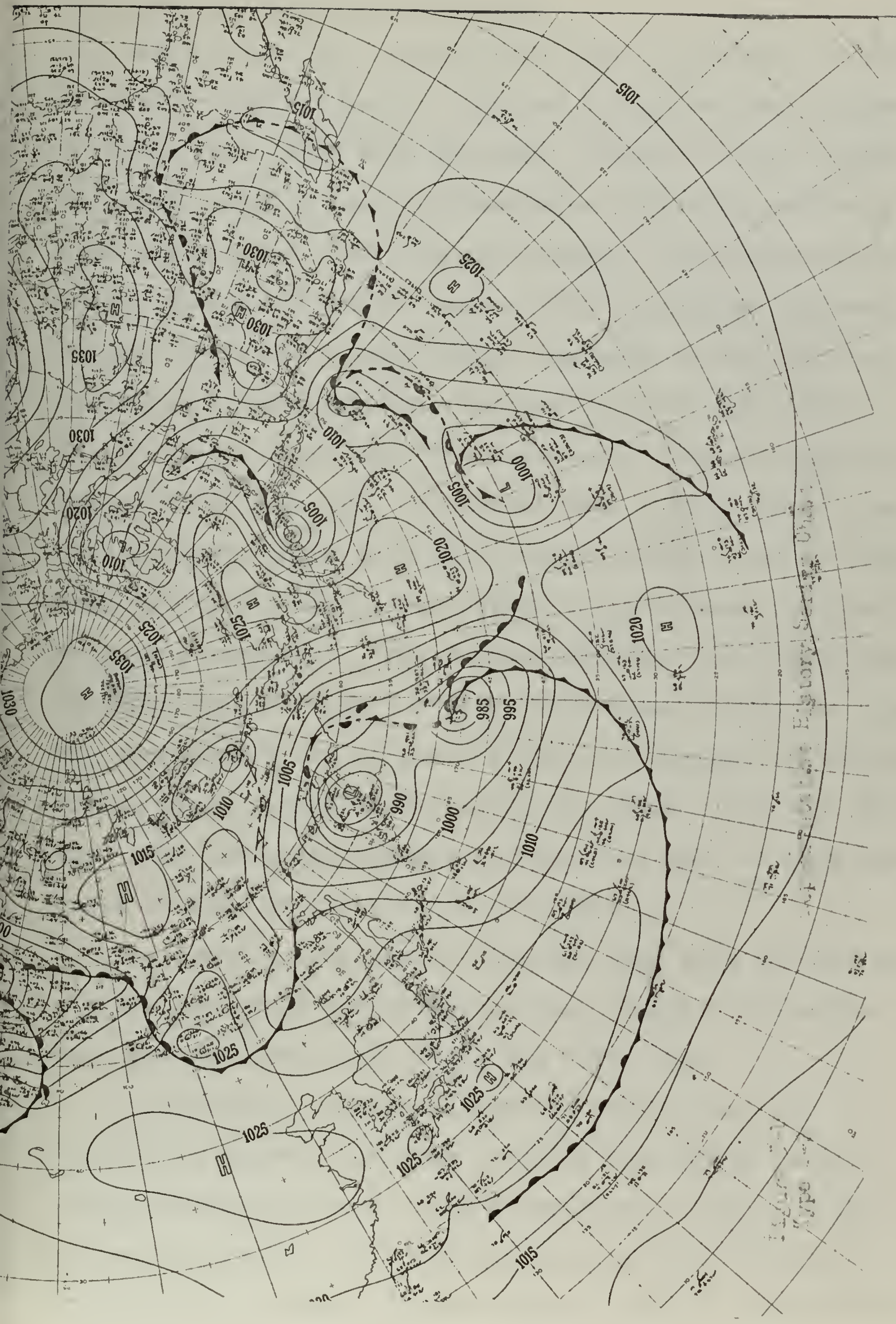
In addition to the predominant blocking system, a distinguishing characteristic of the blocking types is the marked meridional trajectory. The B-2 trajectories generally followed a predominant meridional component just after crossing the 150°E meridian and entered the Bering Sea between the Kamchatka Peninsula and the 180° meridian. Of 31 observed trajectories, eight were observed to follow a trajectory toward the southeast. These were noted to occur in connection with a cut-off low or omega, or simple block at the 500-mb surface. The [illegible] movement was observed at 10° latitude per day for the first twenty-four hour period and decreased to 6° latitude per day following the northward curvature. A region of cyclogenesis east of the 180° meridian was noted similar to that of the meridional-type patterns. In most cases these lows could be identified as Kona lows and were also associated with simple or omega blocks and cut-off lows. The center of the area of cyclogenesis for eight of these Kona lows was estimated to be 30°N latitude and 165°W longitude. The cyclone trajectories of these lows followed a track similar to that of the R-6 type, but displaced 10° latitude to the south (see figure 5-a). The deepening trend of the B-2 type lows indicated a unique rising trend after the second day that oscillated over a 5-mb range thereafter. The amount of deepening was considerably less than the meridional and Z-1 deepening. The pressure gradients as indicated in Appendix IV appear to be several mbs per 5° latitude less than

the meridional or zonal types. However, the B-2 type cyclone models tend to indicate that the zonal gradient is about the same.

The B-2 type fronts indicated a greater deviation than those for any other type, with the frontal wave orientation having a more pronounced SW to NE orientation. The B-2 fronts indicate occlusions of 3° to 8° latitude the second day, increasing to 6° to 13° latitude by the third.

The most noticeable high-pressure feature of the blocking type is the extreme northward position from the mean of the high cells. The B-2 type frequently had a well developed high pressure build-up over Alaska that tended to build a ridge southward near the Aleutian Island chain. The western Pacific high pressure cell was observed to appear near the Kamchatka Peninsula, frequently with a pronounced ridge development towards the south. The central isobar of these highs fluctuated irregularly from day to day between 1020 and 1040 mb. The central isobars of high cells in the eastern Pacific were more stable, with a mean of 1035 mb and an average latitude position near 40°N. The ridge of these east-Pacific high cells was well developed to the south and frequently a ridge connecting the Alaska high was evident. The existence of an Alaskan block was noted in three of seven observed samples.


1035
1040
1020
1000
1010
UNITED STATES AND NORTH PACIFIC
METEOROLOGICAL PLOTTING CHART



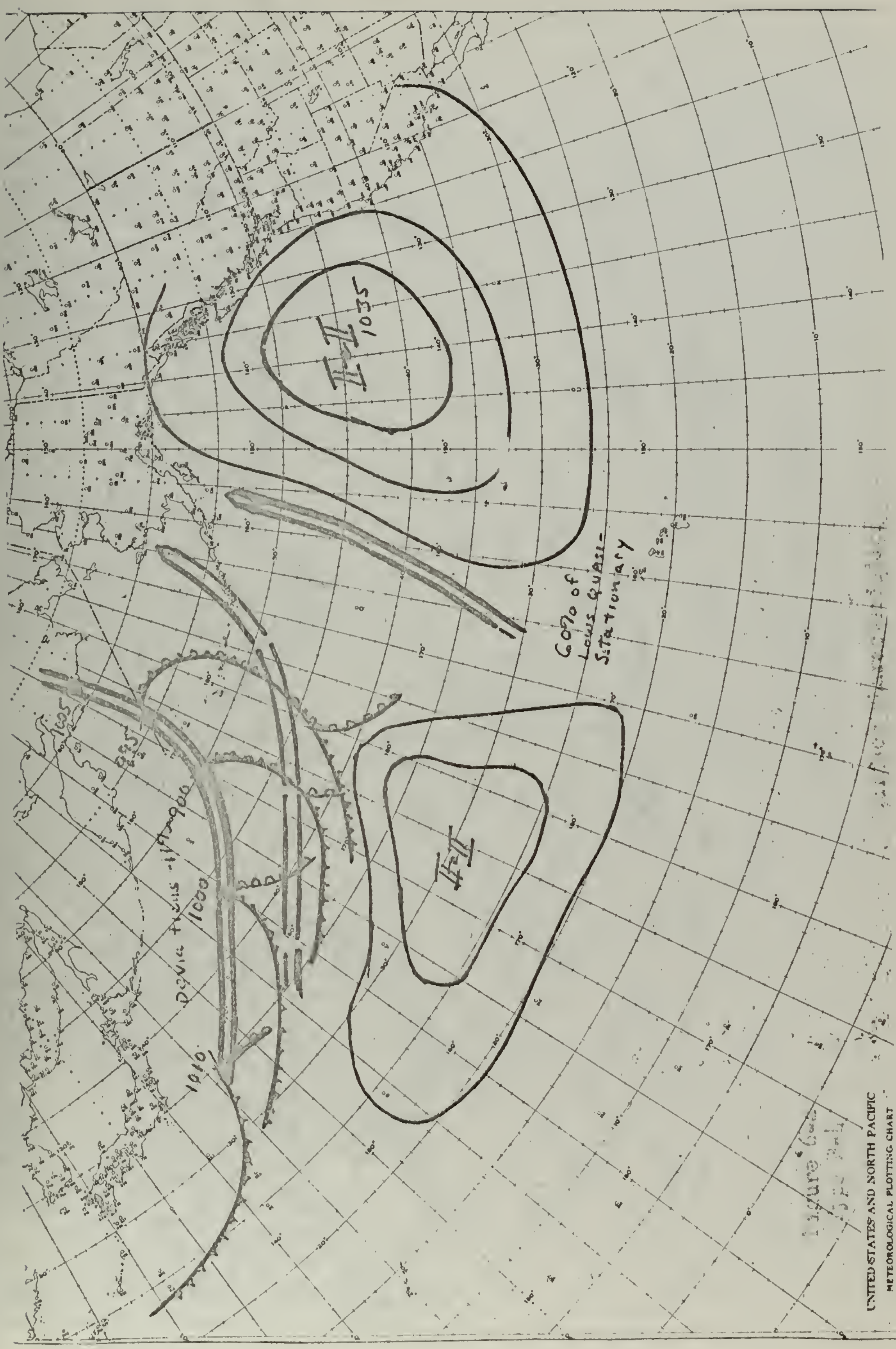
Type B-4 Surface Characteristics

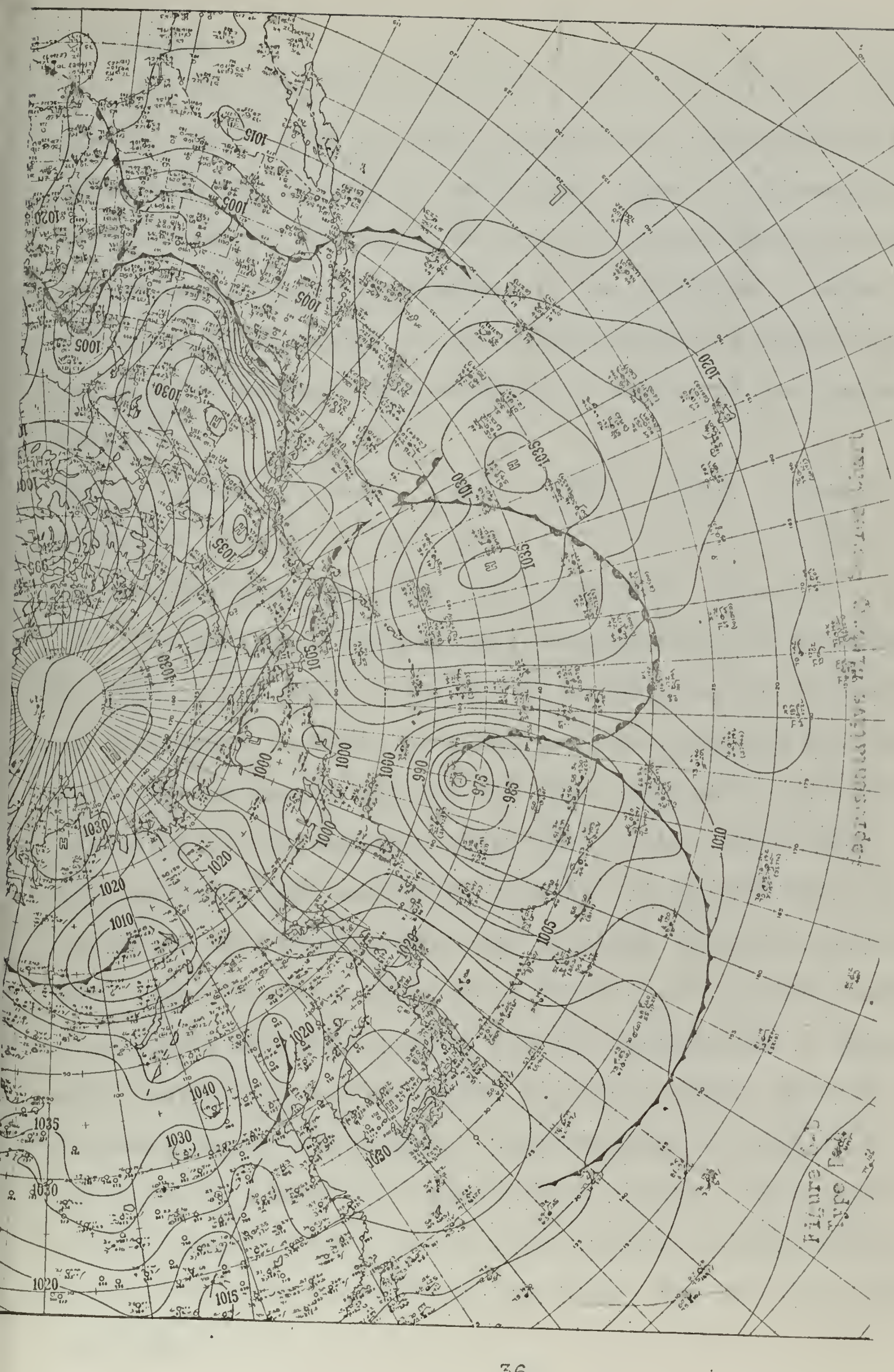
Twenty-eight B-4 trajectories were evaluated as compared to thirty-five B-2 paths. The B-4 trajectory was observed to split near Japan with one path, similar to that of the B-2 type, passing near the Kamchatka Peninsula and the eastern-most leg passing east of Adak, Alaska. The trajectories associated with cyclogenesis east of 180° longitude followed an extreme meridional component as compared to the B-2 type trajectories, terminating near the beginning of the Aleutian Island chain. (See Fig. 5-a and 6-a). Of the twenty-eight observed trajectories, associated with Asiatic east-coast cyclogenesis, three were observed to deviate more than 30° from the mean tracks, two towards the southeast and one towards the northwest. The B-4 trajectories associated with the Kona lows were more erratic than those of the B-2 type. The deepening trend of the B-4 type was similar to the meridional type, except that filling was noted after the third day. The pressure-gradient patterns for the B-4 type were quite similar to those for the B-2 type.

The frontal patterns for the B-4 type were similar to the B-2 type with the exception that frontal occlusions were not well developed until the third day.

A noticeable difference between the B-2 and B-4 blocking highs was the less frequent occurrence of the Alaska block, with only one occurrence of a block in six evaluated periods. The western Pacific high lobe was observed with a modal central-isobar value of 1020 mb at a mean latitude of 30°N. The Eastern Pacific block was noted

to be quite stationary, the mean latitude position being 45°N and the central-pressure average between 1035 and 1040 mb. A well-developed ridge extended south or southwestward.


UNITED STATES AND NORTH PACIFIC
METEOROLOGICAL PLOTTING CHART
60% of Lows Quasi-Stationary
1035
1000
1010



5. Summary

The most frequently occurring types observed were the blocking types with 159 days, followed by 151 days of the zonal type and 93 days of meridional types. The resultant factor obtained by taking the ratio of total number of days to the total number of observed tracks produced a value that corresponded favorably to the period histogram which Elliott [1, p.17] obtained. The results for each type are indicated below:

Type:	Z-1	Z-4	R-5	R-6	B-2	B-4
Factor:	6	3	3	7	2	3

In the R-6 type case, only six tracks were evaluated.

The preceding weather-type descriptions are summarized in Table 1 and Figs. 7 and 8. In determining an estimation of confidence in these evaluations, consideration must be given to the sample size of the types evaluated and the reliability of the analyzed historical series daily maps. Particularly, the sparseness of data and subjectivity in analyzing over ocean areas must be given careful attention. The larger reporting network of stations, increased number of aircraft and ship reports and the development of upper-air observations have resulted in more reliable analyzed and forecast charts since 1940. Since Holland and Mills [7, Appendix III] used these more recent charts, their system of weather typing should have a more reliable foundation than those of earlier pioneers in the field, who used data from the 1930s.

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

[illegible]

Generally, the reliability of the pressure-gradient observations may be noted to decrease as the age of the cyclone increases and as the distance from the center increases. In the case of types such as the A-6 type where the frequency of type occurrences was small, the cluster or spread had to be used to determine the degree of confidence.

TABLE 1: Summary of Type Characteristics

		Z-1	Z-4	F-5	K-6	E-	E-4
Mean Location of Cyclogenesis off Asiatic Coast		32°N 138°E	33°N 149°E	36°N 146°E	34°N 144°E	38°N 144°E	34°N 146°E
Initial Central Isobar Pressure, in mb.		1015	[illegible]	1010	1010	1010	1010
Trajectory, Mean Latitude of Meridian Crossing	150°	37°N	35°N	36°N	36°N	39°N	37°N
	180°	43°N	[illegible]	47°N	43°N	No Crossing	37% at 45° 54% no Crossing
Nodal Speed of Advance in °lat/day	1st day	14	10	10	16	10	14
	2nd day	15	15	11	16	[illegible]	11
	3rd day	14	[illegible]	[illegible]	13	[illegible]	6
	4th day	[illegible]	[illegible]	[illegible]	9	[illegible]	6
Nodal Pressure Change in mb/day	1st day	-5	-5	-15	-15	-10	-10
	2nd day	-20	-10	-10	-10	[illegible]	-10
	3rd day	-25	-15	0	-5	-5	+ [illegible]
	4th day	+ [illegible]	[illegible]	+5	0	[illegible]	+10
First Day of Occlusion		3rd	4th	3rd	3rd	2nd	3rd
and Mean Length in °lat		12	6	[illegible]	7	6	9

TABLE 1 (Continued)

				Z-1	Z-4	[illegible]-5	[illegible]-6	[illegible]-2	[illegible]-4
[illegible] pressure difference from center to ___, in mb[1]		1st day	5°	[illegible]	[illegible]	[illegible]	7	[illegible]	[illegible]
			10°	11	15	12	10	[illegible]	[illegible]
		2nd day	5°	[illegible]	12	[illegible]	[illegible]	[illegible]	[illegible]
			10°	[illegible]	17	[illegible]	[illegible]	[illegible]	[illegible]
		3rd day	5°	[illegible]	15	[illegible]	11	[illegible]	[illegible]
			10°	[illegible]	24	[illegible]	11	[illegible]	[illegible]
		[illegible] day	5°	[illegible]	14	[illegible]	[illegible]	[illegible]	11
			10°	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible] Subtropical High Cell	East lobe	mean latitude position		[illegible]	32°N	37°N	[illegible]	40°N	45°N
		central [illegible] in mb		[illegible]	[illegible]	1030	[illegible]- 1030	[illegible]	1035- 1040
	West lobe	mean latitude position		31°N to 26°N	30°N to 25°N	[illegible]	27°N	31°N to 18°N	30°N
		central [illegible] in mb		1020	1020	[illegible]	[illegible]- [illegible]	[illegible]- [illegible]	[illegible]
[illegible] Location of [illegible] [illegible] 160°						37°N 168°W	36°N 174°W	34°N 165°W	31°N 166°W

[1] [illegible] differences were evaluated along a meridian due south from the cyclone center for 0 to 5°, 0 to 10° and 0 to 15° latitude increments.

[2] The type B-2 also has a pronounced ridge extending southward from the Alaskan High near the Aleutian Island chain nearly 40% of the time

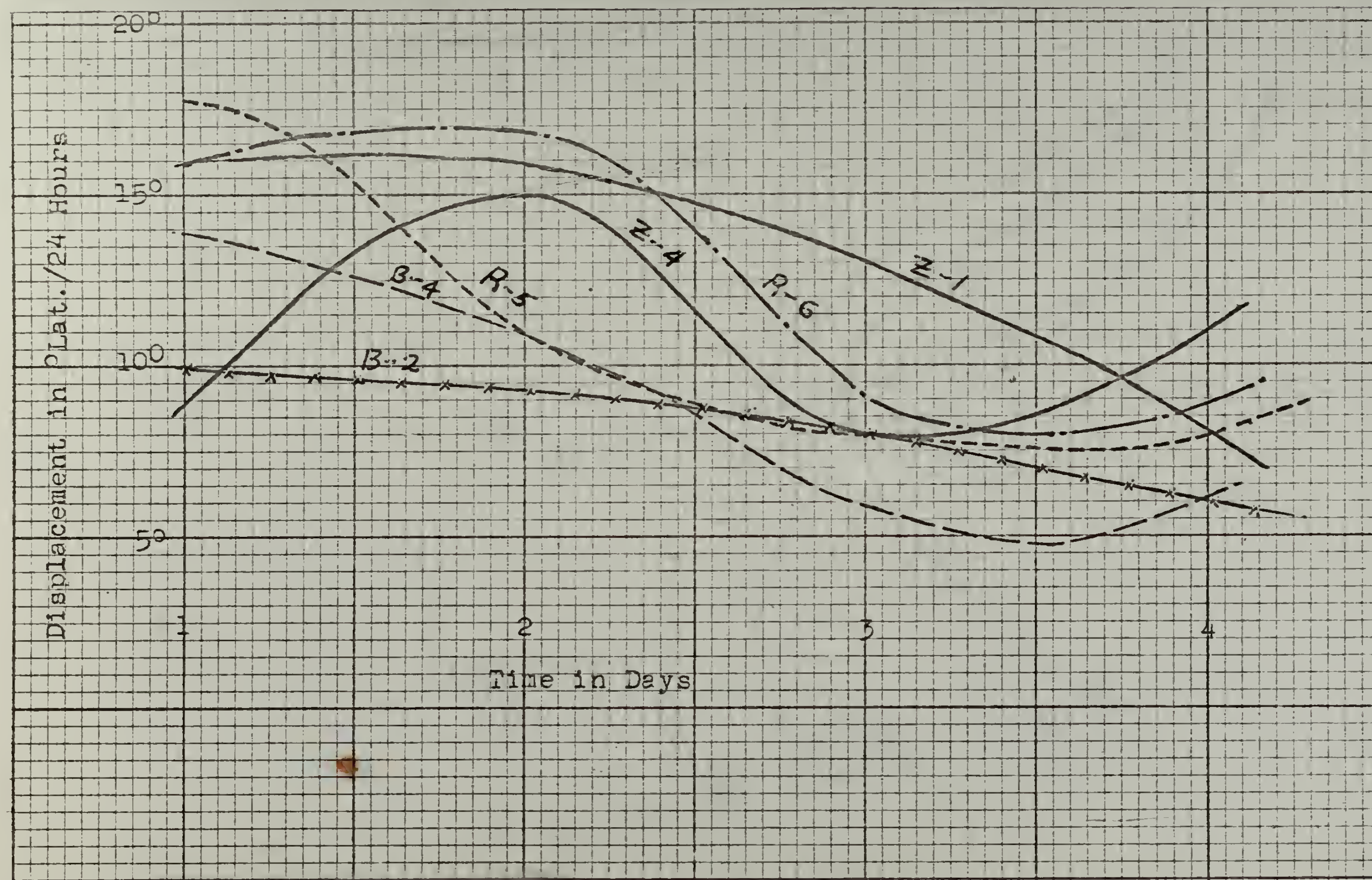
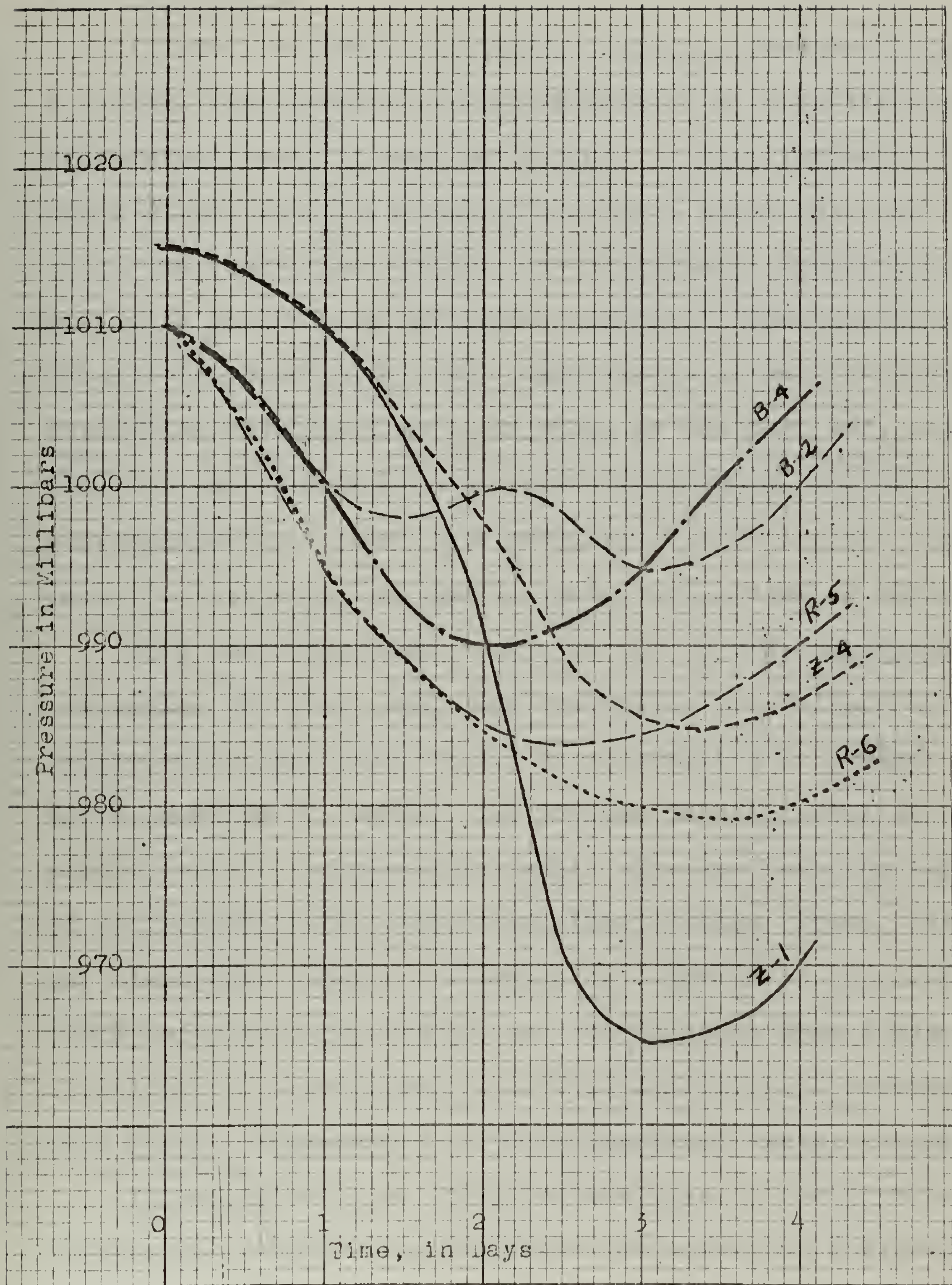


Figure 7: Trend graph of 24-hour Displacement


1020
1010
1000
990
980
970
Pressure in Millibars
0
1
2
3
4
Time, in Days
B-4
B-2
R-5
Z-4
R-6
Z-1

6. Conclusions

It must be clearly apparent that this research is only a partial step towards the perfection of an operative forecast method based on weather typing. It is limited in its areal extent and the seasonal coverage, since only the Pacific area and winter months were evaluated. Consideration must also be given to the small number of types evaluated, which were restricted by the sample size of each sub-type. Inspection revealed that such types as the Z-2, Z-3, R-4, B-5, B-6, and B-7 had a very small occurrence frequency, particularly in January and February, indicating the importance of a seasonal, or even monthly, break-down of these types.

With the additional data that can be made available by expanding the year group and evaluating for Holland and Mills types, sufficient data should be accumulated to analyze other types, as well as to extend the present investigation to other sectors and to increase the sample size and thus the degree of confidence in the types described in this paper. Also the similarity between all types as observed in the 120°E to 170°E sector of the Pacific tend to indicate that a six-sector division of the Hemisphere, such as Selfridge, Stevenson, and Wood [10] suggested, is a more practical sector arrangement.

In retrospect, an objective analysis of the upper-air influences, temperature structure for advective influences, and the broad-scale flow characteristics that exist between the high and low-pressure cells would give additional valuable information in the development of a more complete and useful

[illegible]

forecast method. Present-day computer methods, such as used by Selfridge, Stevenson, and Wood [10], could be programmed to include this information; this could be particularly useful in the development of least-time tracks, used by the Optimum Ship Routing Program.

Since no comparison has been made to the observed 500-mb parameters, it is recommended that further efforts in this field be directed to correlating parameters such as temperature, pressure and contour gradient at the surface and 500-mb, surface lows and upper-level waves, and frontal characteristics.

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APPENDIX I

Elliott's Pacific Weather Types

Table of Elliott 1 Pacific weather types and corresponding Holland and Mills 7 types

Elliott	season of maximum occurrence	zonal features	Holland and Mills
B	summer	zonal	Z-1[1]
B_s	winter	meridional	R-5
B_n	summer	meridional	R-6
A	------	meridional	B-2[2]

1. Type Z-1 trajectory is located 5° to 15° of latitude farther south, corresponding to seasonal differences.
2. The Siberian high extending over the Bering Sea is similar to the type B-2 Alaskan block. The type A trajectory in the vicinity of the Hawaiian Islands occurs in the same area as that of the Kona lows of the type B-2.

APPENDIX II

Table of 24-Hour Displacements in °lat/day

Type		1st	2nd	3rd	4th	Number of Deviations from Mean Track Greater than 30°
Z-1	Mode	16°	20°(16°)	16°(14°)	[illegible]	2
(18)	Range	7-22	8-21	2-19	4-19	
25%	Limit	59%	58%(79%)	73%(80%)	60%	
Z-1N	Mode	8°	6°	7°	8°	3
(5)	Range	5-13	5-17	6-8	---	
25%	Limit	60%	50%	---	---	
Z-4	Mode	9°(11°)	15°	8°	11°	
(15)	Range	6-18	7-23	5-22	3-19	
25%	Limit	67%(75%)	60%	50%	50%	
R-5	Mode	18°	11°	8°	8°(6°)	2
(18)	Range	6-20	4-18	5-18	5-8	
25%	Limit	83%	77%	67%	60%(100%)	
R-5E	Mode	16°(12°)	9°	8°	5°	
(8)	Range	6-18	5-16	7-9	---	
25%	Limit	50%(62%)	71%	---	---	
R-6	Mode	16°	17°(16°)	9°	9°(Ave)	
(8)	Range	11-19	12-20	7-17	5-13	
25%	Limit	87%	87%(100%)	72%	---	
R-6E	Mode	8°	9°	9°	---	
(2)	Range	6-10	9-18	---	---	
25%	Limit	---	---	---	---	
B-2	Mode	10°	9°	8°	6°	6
(35)	Range	4-17	2-18	2-14	3-10	
25%	Limit	85%	73%	70%	73%	
B-2E	Mode	9°	12°	---	---	
(13)	Range	6-22	8-17	---	---	
25%	Limit	77%	---	---	---	
B-4	Mode	14°	11°	6°	6°	2
(28)	Range	1-19	2-19	2-15	2-11	
25%	Limit	71%	58%	65%	64%	

Values in Parentheses indicates best 25% limit score value.

N = North E = East

APPENDIX III

Table of 24-hour Central-isobar change

Type		Initial Pressure	1st	2nd	3rd	4th
Z-1 ±5mb	Mode Range Limit	1015 mb 1005-1025 67%	-5 -30-0 67%	-20 0 to-30 56%	-25 +10 to-30 40%	+5 +10 to-25 60%
Z-1 North ± 5mb	Mode Range Limit	1010 mb 1000-1020 60%	-5 -5 to-20 60%	-10 +5 to-15 75%	---- -5 to-30 ----	0 ---- ----
Z-4 ± 5mb	Mode Range Limit	1015 mb 1005-1015 80%	-5(-10) -5 to-30 58%(63%)	-10 +5 to-30 62%	-15 +10 to-35 47%	0 +15 to-10 63%
R-5 ±5mb	Mode Range Limit	1010 mb 975-1015 67%	-15 +5 to-30 74%	-10 +10 to-30 64%	00(+5) +5 to-15 50%(62%)	+5 +10 to-10 80%
R-5 East ±5mb	Mode Range Limit	1010 mb 990-1010 75%	-5 -15 to+5 75%	0 -20 to+10 57%	---- 0 to-10 ----	---- ---- ----
R-6 ± 5mb	Mode Range Limit	1010 mb 1010-1020 80%	-15 -5 to-25 63%	-10 -5 to-35 63%	-5 5 to-15 71%	0 0 to-5 ----
B-2 ±5mb	Mode Range Limit	1010 mb 995-1015 80%	-10 +5 to-50 69%	0 -15 to+15 59%	-5 -10 to+25 37%	0 -15 to+10 36%
B-2 East ±5 mb	Mode Range Limit	1000 mb 985-1015 46%	-5 +5 to-10 69%	---- 0 to -5		
B-4 ±5mb	Mode Range Limit	1010 mb 995-1015 82%	-10 +5 to-35 61%	-10 +10 to-30 54%	+5 +15 to-20 50%	+10 0 to 10 72%

[illegible]

APPENDIX IV

COMPARISON TABLE OF PRESSURE DIFFERENCES

Horizontal Unit or length in $^\circ$Lat[1]	DAY 1			DAY 2			DAY 3			DAY 4			DAY 5		
	5°	10°	15°	5°	10°	15°	5°	10°	15°	5°	10°	15°	5°	10°	15°
TYPE															
Z-1 Mode	8	11	12	13	19	25	17	28	33	20	34	52	18	34	43
(19) Range	4-14	4-17	7-22	6-21	10-34	8-47	5-30	8-50	12-58	7-30	13-52	21-67	13-20	20-42	26-55
95% Limit	65%	71%	65%	79%	74%	58%	84%	79%	68%	67%	73%	73%	---	---	---
Z-4 Mode	8	15	7	12	15	19	15	24	30	14	27	36	10	22	34
(16) Range	3-10	3-16	2-20	5-16	8-29	11-39	7-18	9-34	9-35	9-28	6-46	9-56	6-24	16-38	17-47
Limit	82%	64%	64%	81%	71%	50%	81%	69%	75%	67%	67%	73%	71%	73%	71%
B-2 Mode	4	10	10	10	17	24	9	11	20	10	19	25	12	14	17
West Range	2-9	6-15	1-21	4-20	7-38	3-55	3-32	8-43	10-51	5-20	9-35	11-41	5-20	11-36	5-46
(29) Limit	76%	69%	48%	72%	59%	74%	73%	61%	65%	50%	47%	47%	61%	50%	53%
E-4 Mode	6	8	11	9	14	17	12	23	26	11	19	32	21	36	47
(24) Range	2-14	4-20	1-24	2-25	5-30	3-35	6-32	13-46	13-53	7-33	9-42	15-60	10-24	19-41	26-48
Limit	65%	60%	61%	80%	76%	75%	70%	67%	65%	67%	58%	58%	71%	65%	71%
R-5 Mode	6	12	18	13	20	24	15	28	32	12	29	40	14	30	39
(15) Range	4-17	4-29	3-29	5-18	16-32	14-36	4-31	10-50	9-53	9-25	15-38	21-43	12-22	24-46	30-47
Limit	67%	58%	50%	80%	93%	60%	77%	77%	77%	60%	70%	70%	60%	80%	80%
R-6 Mode	7	10	12	10	19	24	11	21	25	15	24	35	12	24	32
(6) Range	4-7	6-14	5-15	4-13	3-23	3-28	2-22	12-42	19-35	4-20	13-37	19-41	---	---	---
Limit	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

[1] As measured from center of cyclone due south

Number in parenthesis indicates sample size

APPENDIX V

HISTOGRAMS OF DISPLACEMENTS, CENTRAL-ISOBAR TENDENCY, AND PRESSURE GRADIENTS

Histograms of cyclone displacement, central-isobar pressure change, and pressure gradient are included as a graphical representation of the distribution and deviation of the parameter evaluated.

The histogram of cyclone displacement indicates the 24-hour displacement of the cyclone center for each of the four periods for the six types. Each ordinate unit indicates a single occurrence. The abscissa units represent $2\frac{1}{2}^{\circ}$ lat/day increments.

The histogram of central-isobar pressure change represents the 24-hour change of pressure for the corresponding periods and types. The ordinate units, as before, represent a single occurrence and the abscissa indicates the pressure change, deepening, filling, or no change in 5 mb increments.

The pressure-gradient histograms denote the distribution for the five days observed for each type and for latitude increments of 5°, 10°, and 15° as measured due south from the low center. The ordinate unit represents a single occurrence, and the abscissa unit of measure is 5 mb of pressure difference relative to the center.

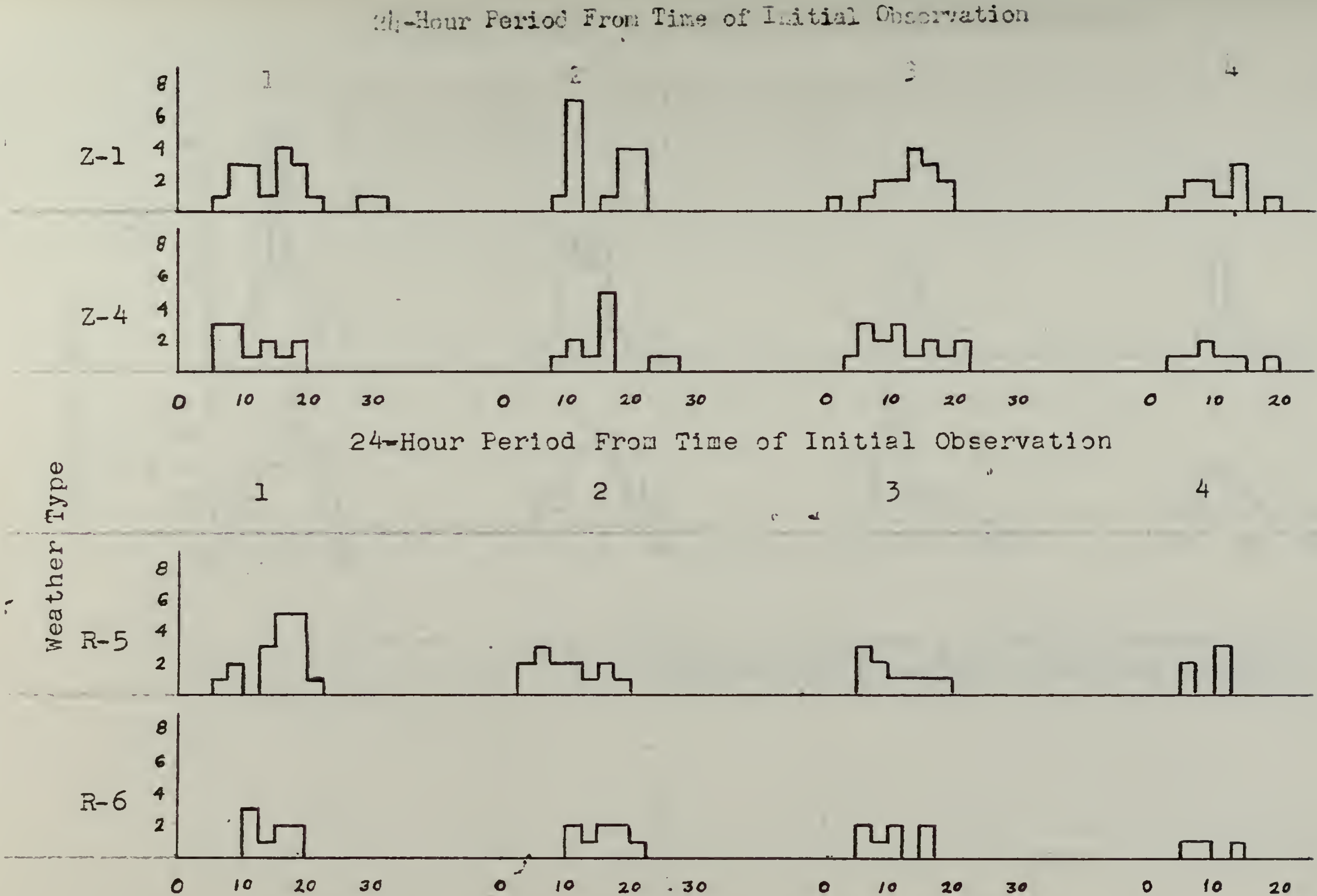


Fig 9: Histogram of 24-Hour Movement of Cyclones Originating in Western Pacific

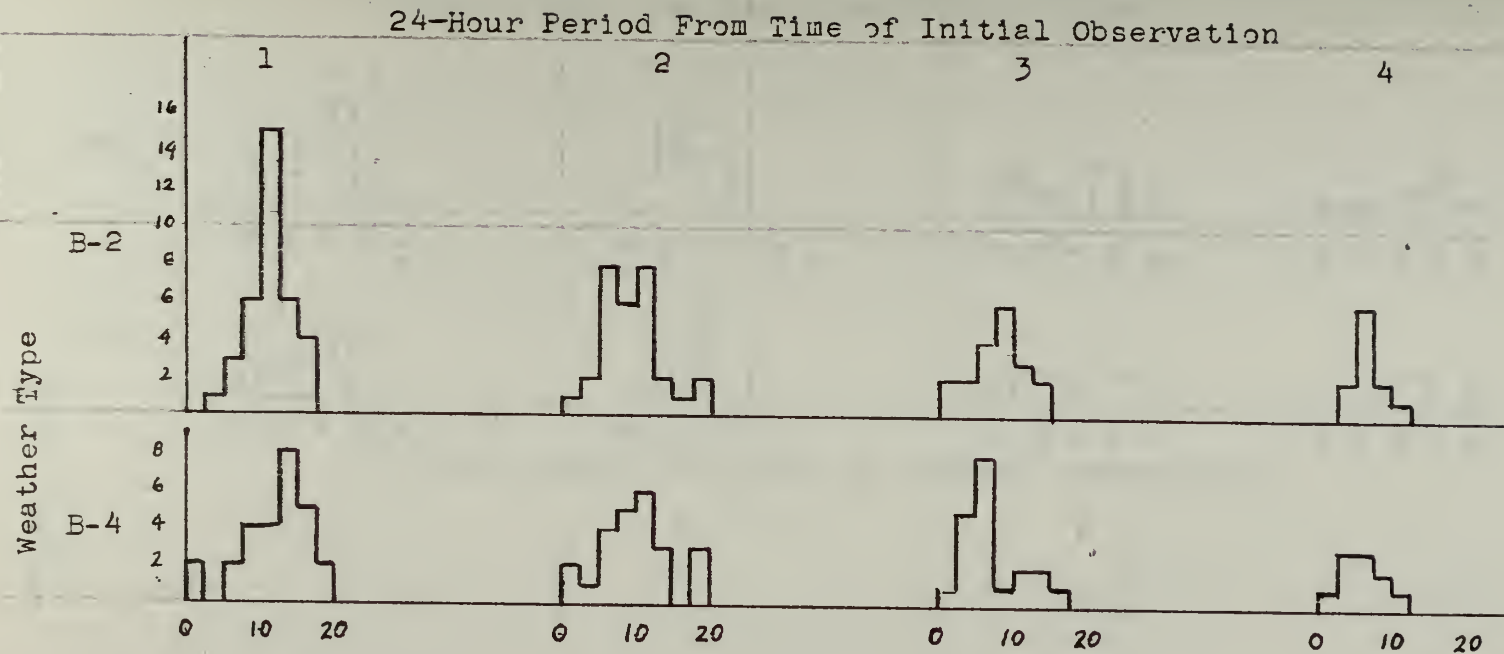


Fig 9(Cont.): Histogram of 24-Hour Movement of Cyclones Originating in Western Pacific

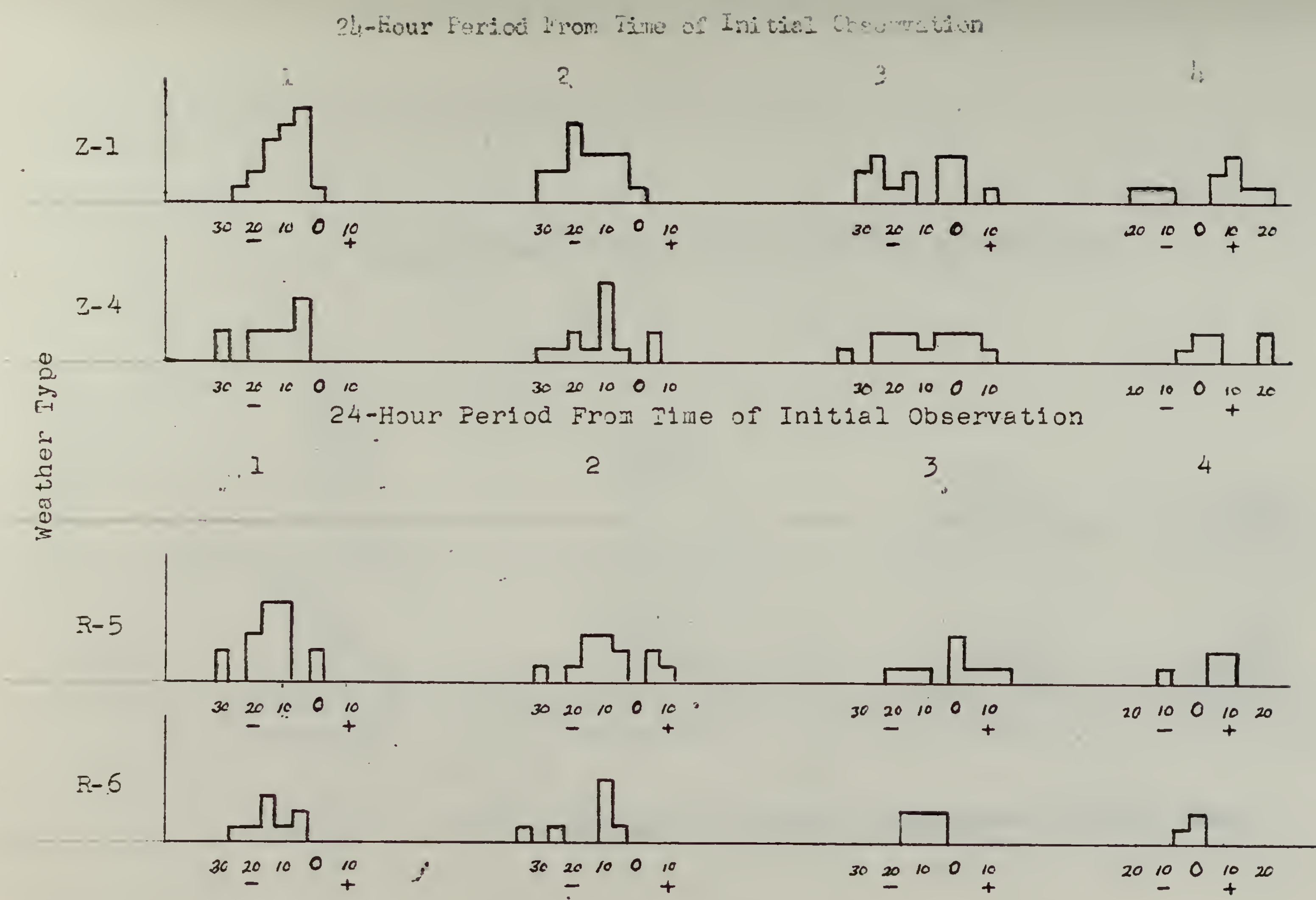


Figure 10: Histogram of 24-Hour Central-Isobar Pressure Change

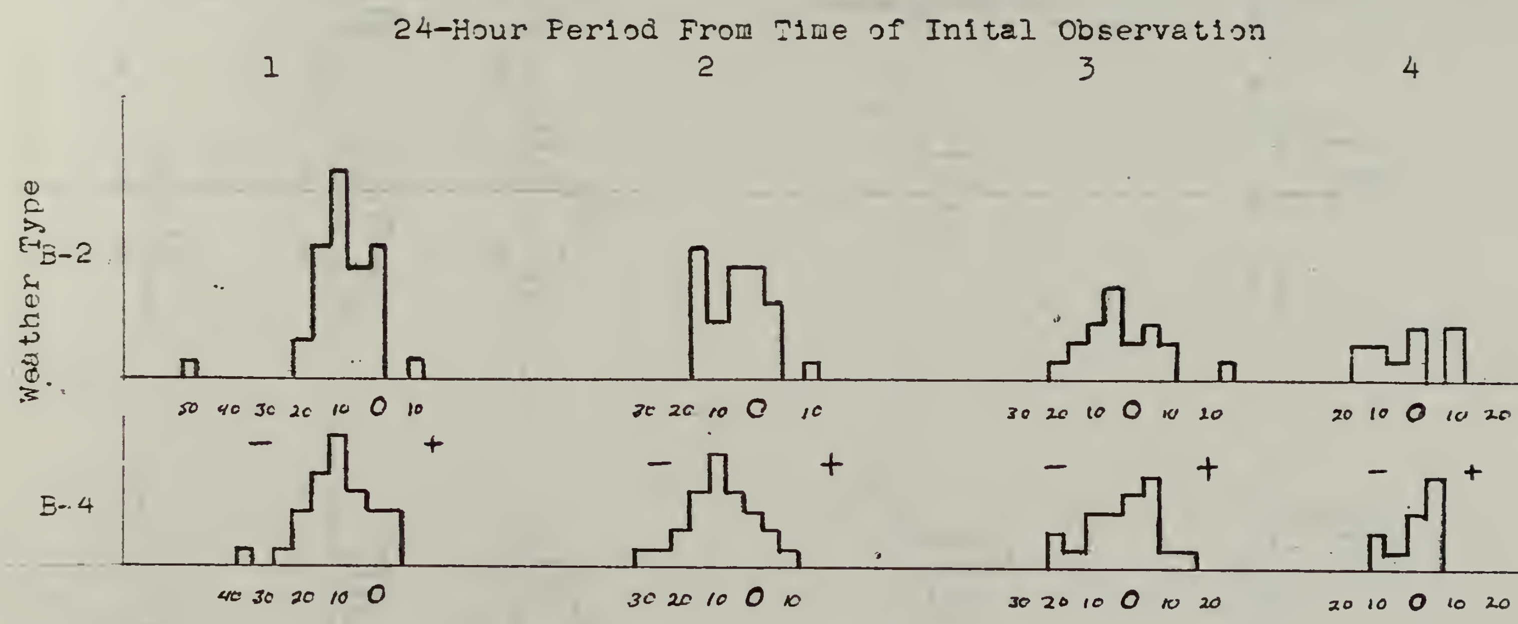


Figure 1[illegible] (Cont'd): Histogram of 24-Hour Central-Isobar Pressure Change

Figure 11: Histogram of Type Z-1 Pressure Gradients

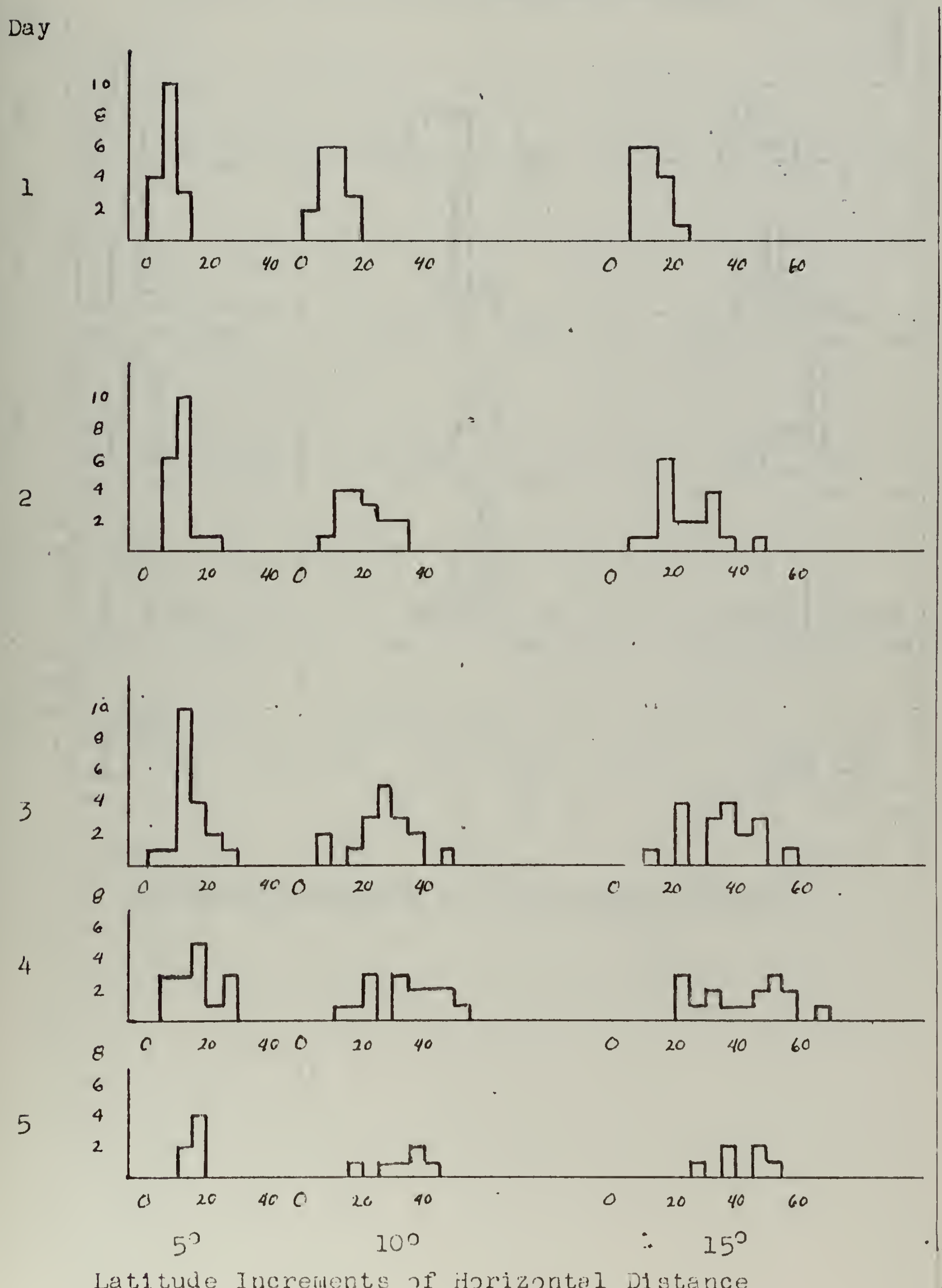


Figure 12: Histogram of Type Z-4
Pressure Gradients

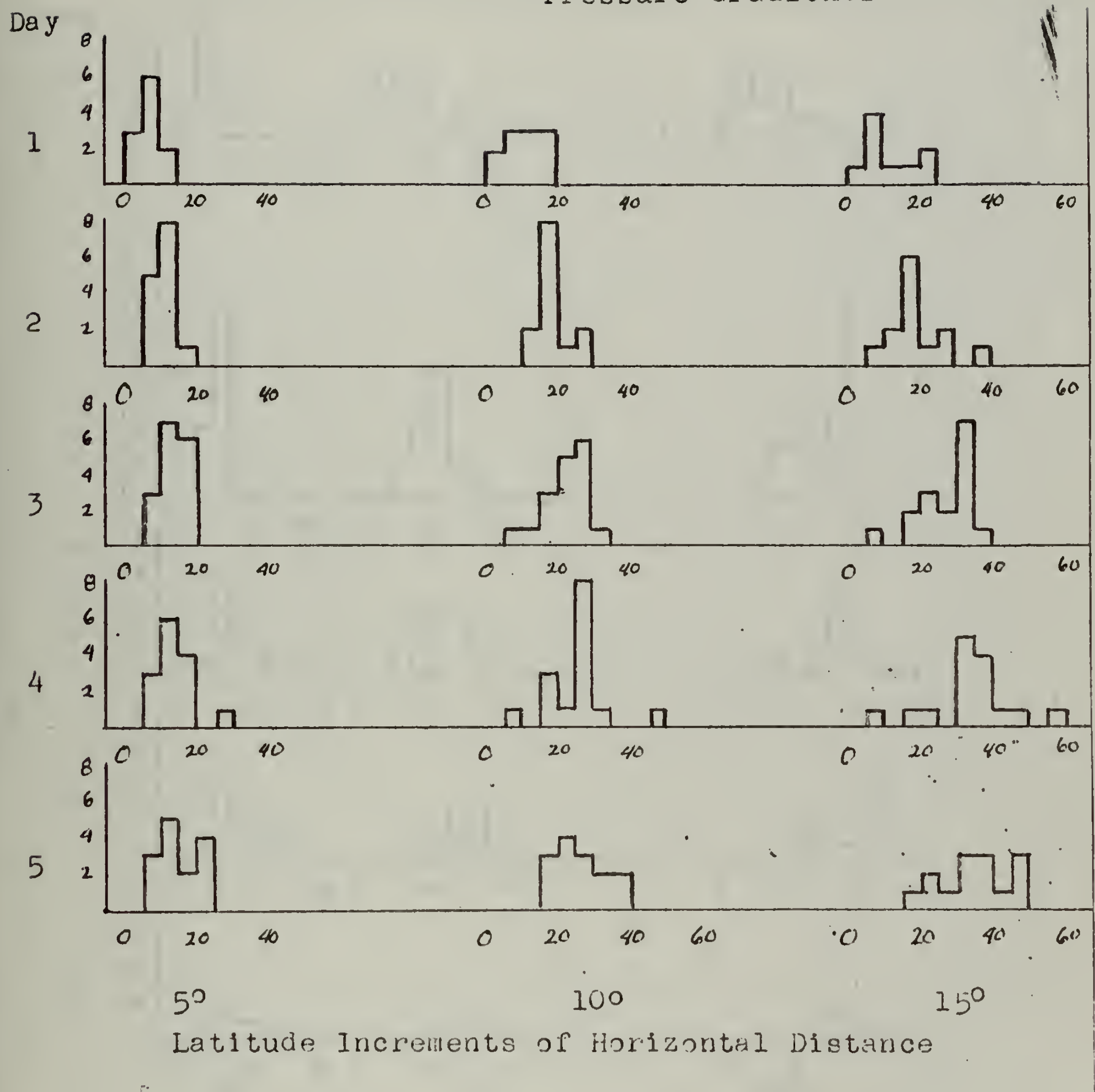
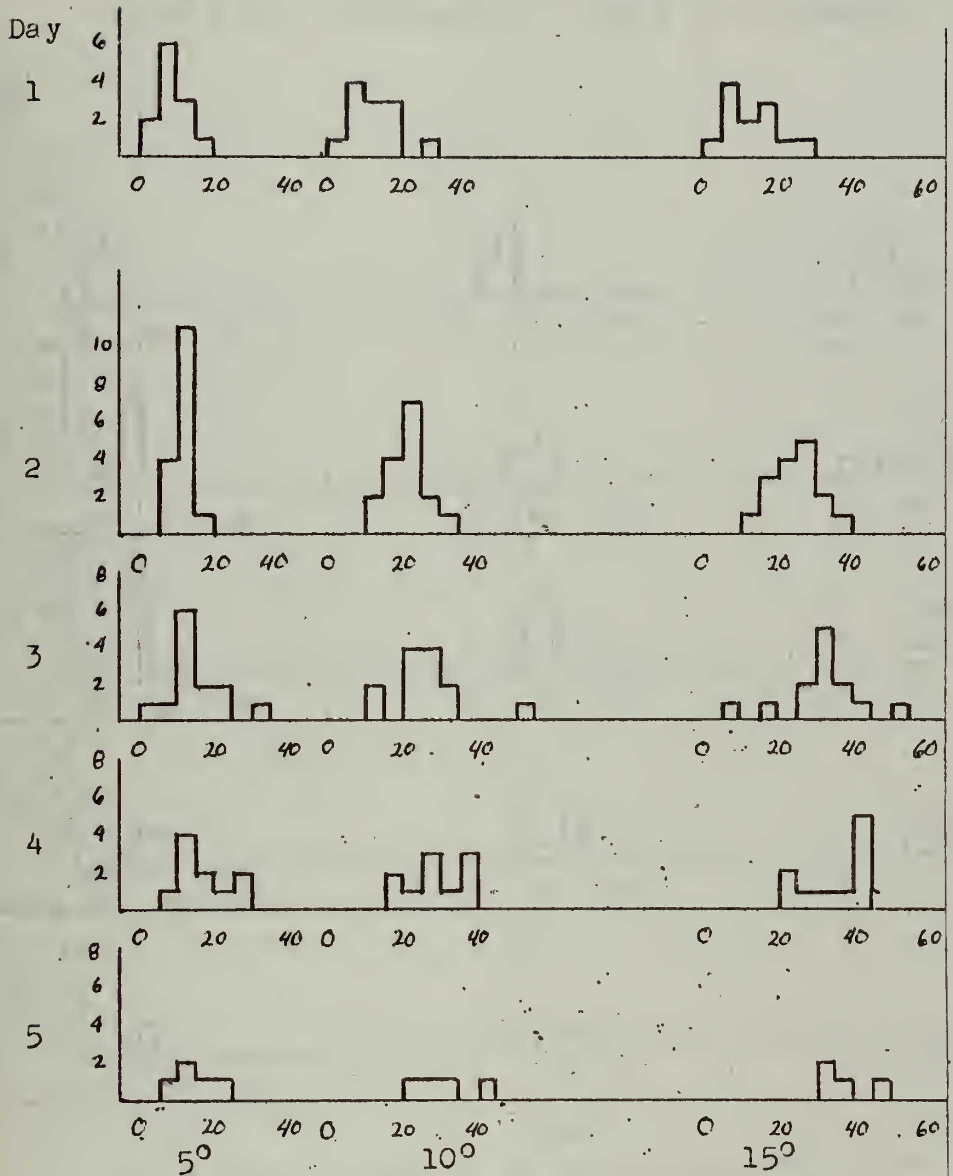
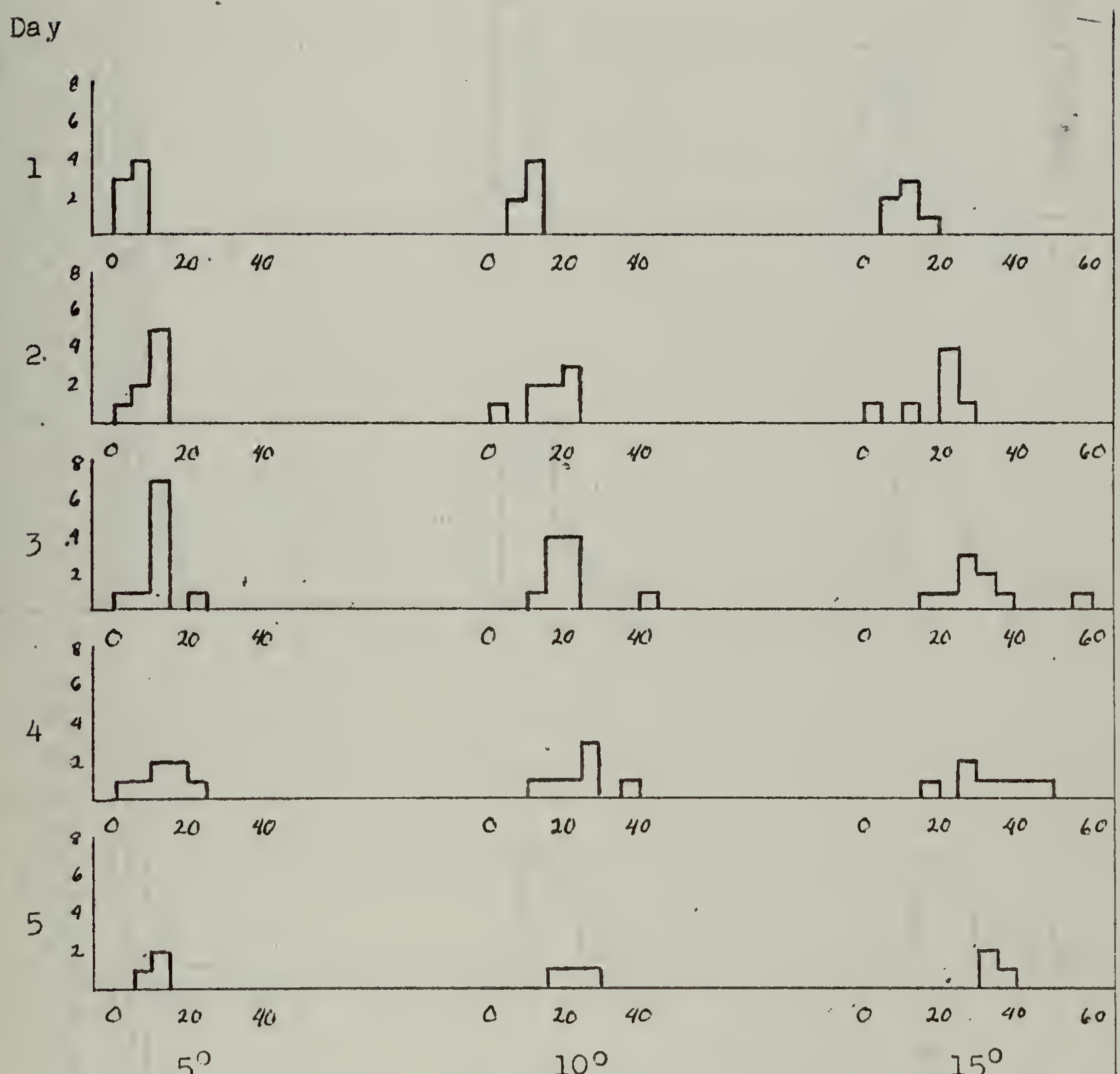


Figure 13: Histogram of Type R-5 Pressure Gradients



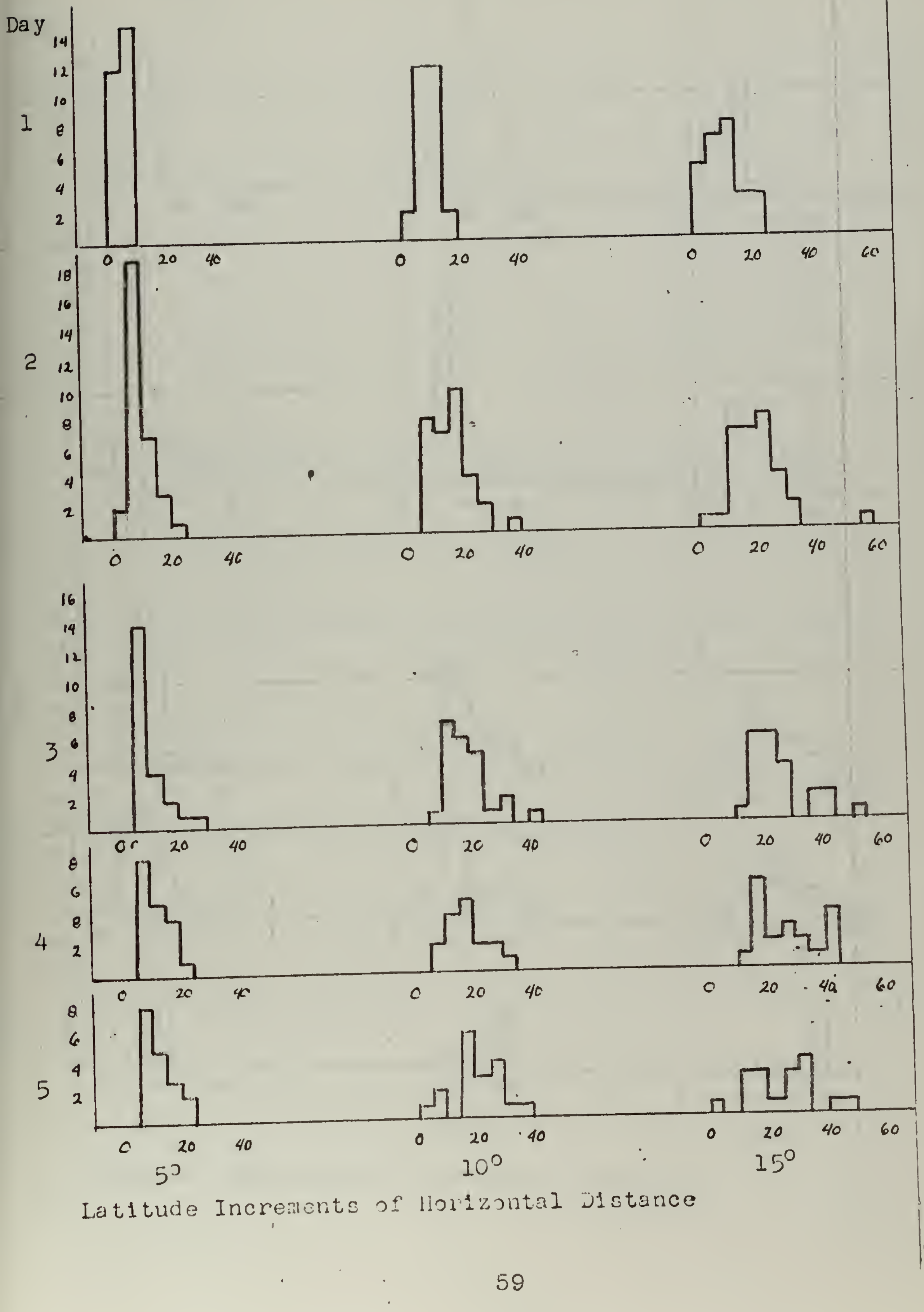
Latitude Increments of Horizontal Distance

Figure 14: Histogram of Type R-6 Pressure Gradients



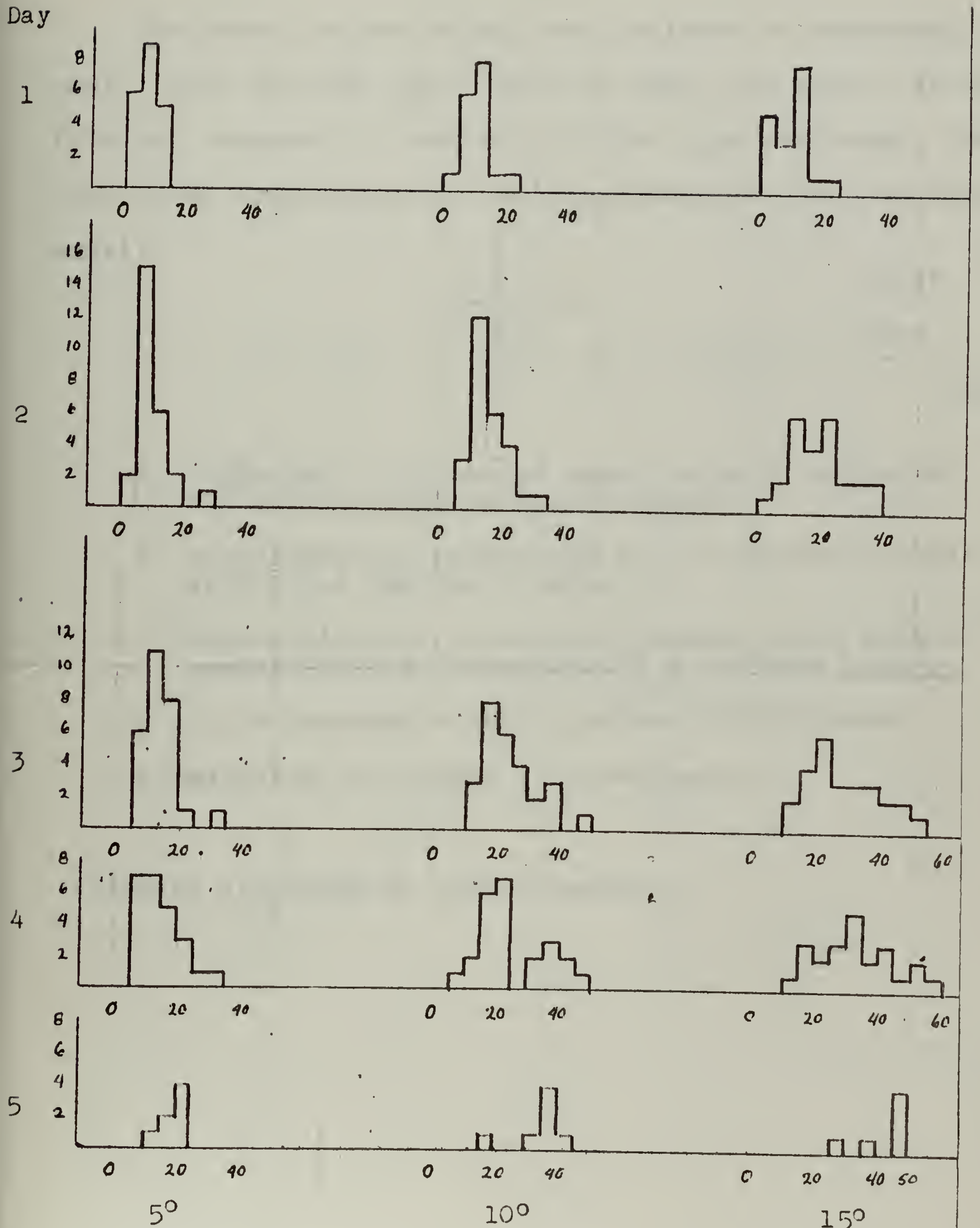
Latitude Increments of Horizontal Distance

Figure 15: Histogram of Type B-2 Pressure Gradients



Latitude Increments of Horizontal Distance

Figure 16: Histogram of Type B-4 Pressure Gradients



Latitude Increments of Horizontal Distance

APPENDIX VI

The modal cyclone models are included to represent the mode, range and 25% limit value at each grid point for the five-day sequence of each of the six types evaluated. The grid value representation is illustrated in the following model:

B	A	Type
C	D	Day
		(E)

A indicates the observed modal value of pressure difference relative to the center.

B represents the percentage of the observed sample within the 25% limit value.

C is the minimum pressure-difference value of the sample, and is occasionally a negative number.

D is the maximum value of pressure difference.

E indicates the sample size evaluated.

Isobars are drawn at 4-mb intervals.

Figure 17-a: Type Z-1 Modal Cyclone Model for First Day

(17)

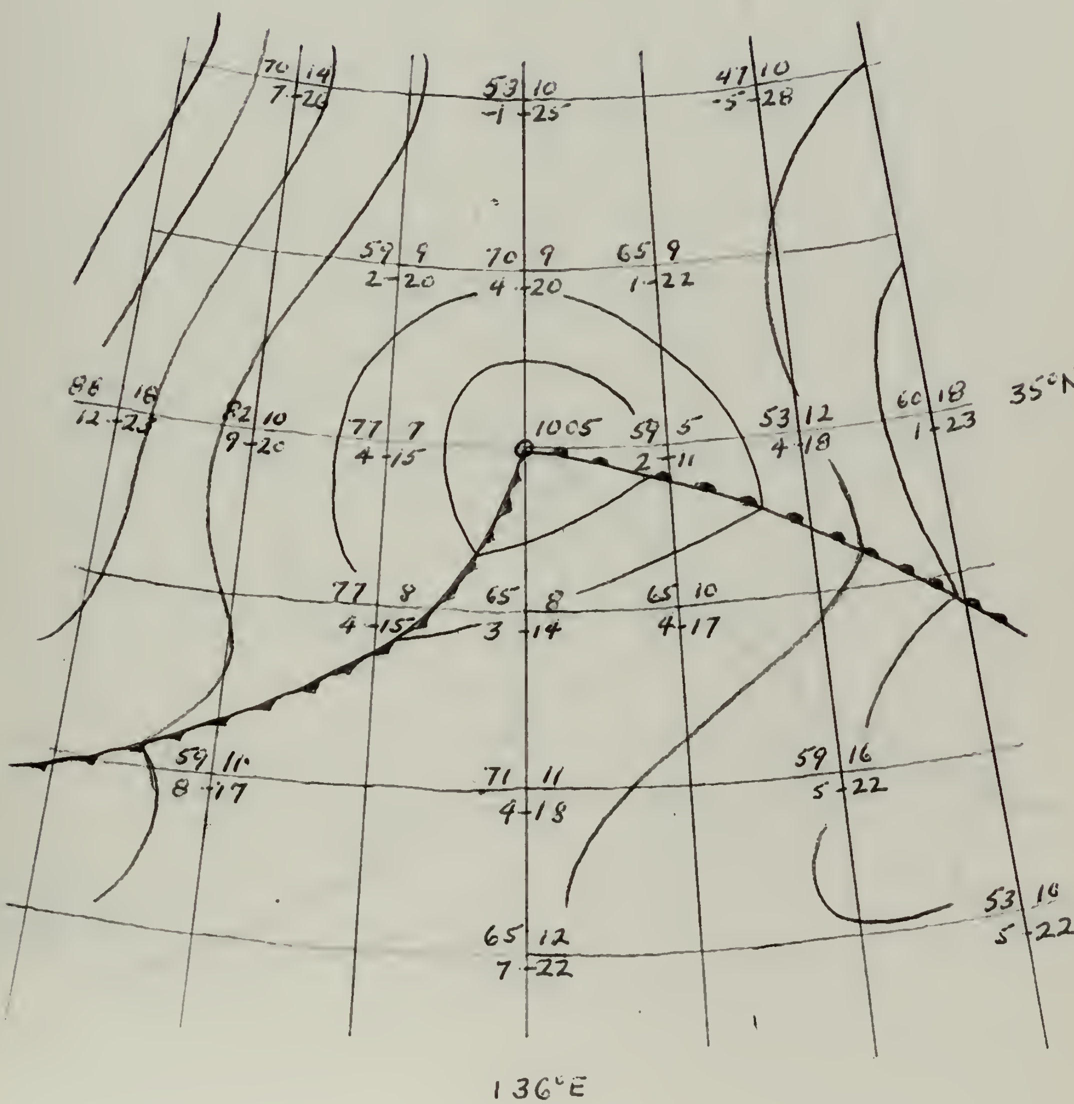


Figure 17-b: Type Z-1 Modal Cyclone Model for Second Day

(19)

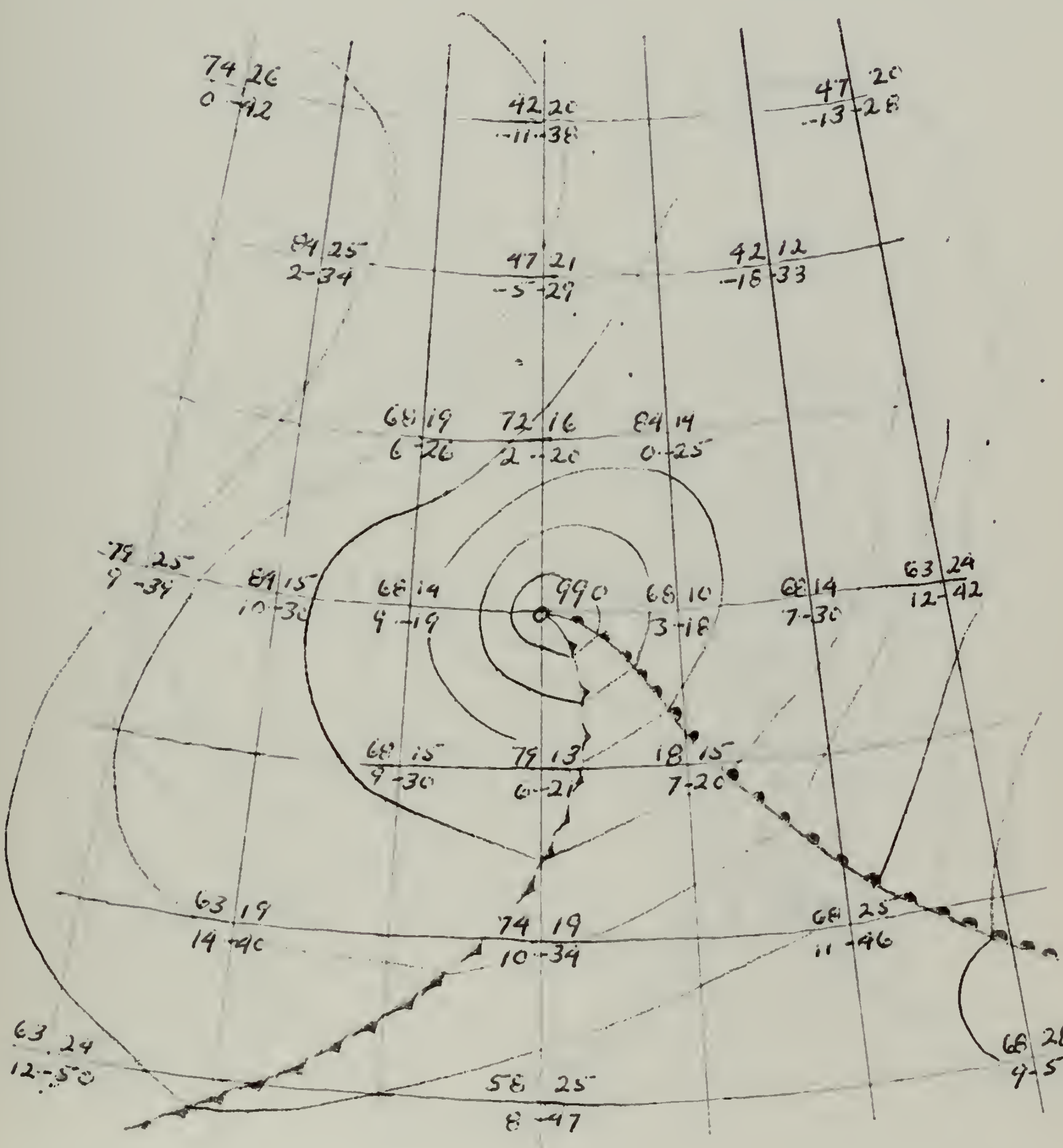


Figure 17-c: Type Z-1 Modal Cyclone Model for Third Day

(19)

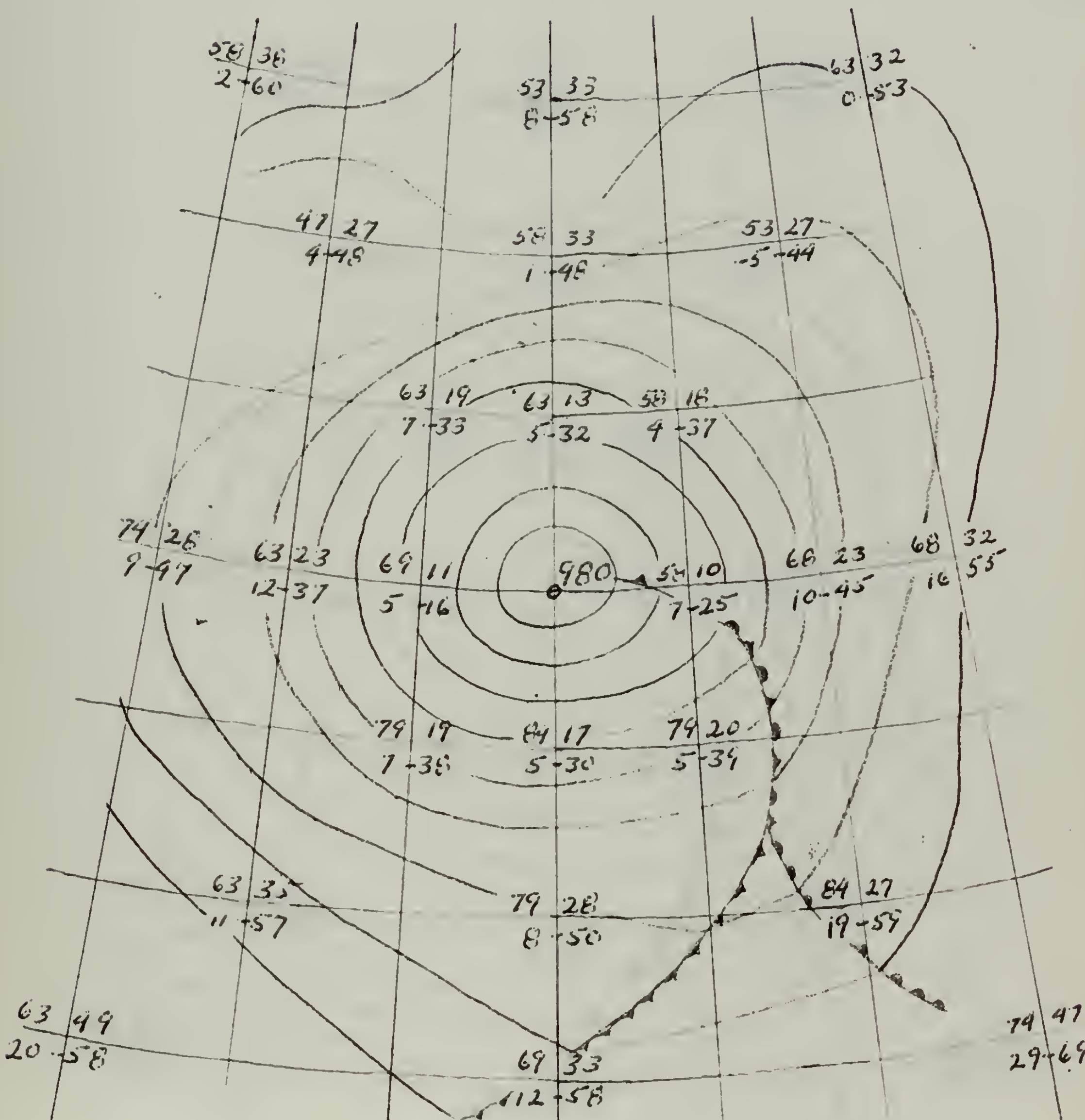


Figure 17-d: Type Z-1 Modal Cyclone Model for
Fourth Day

(14)

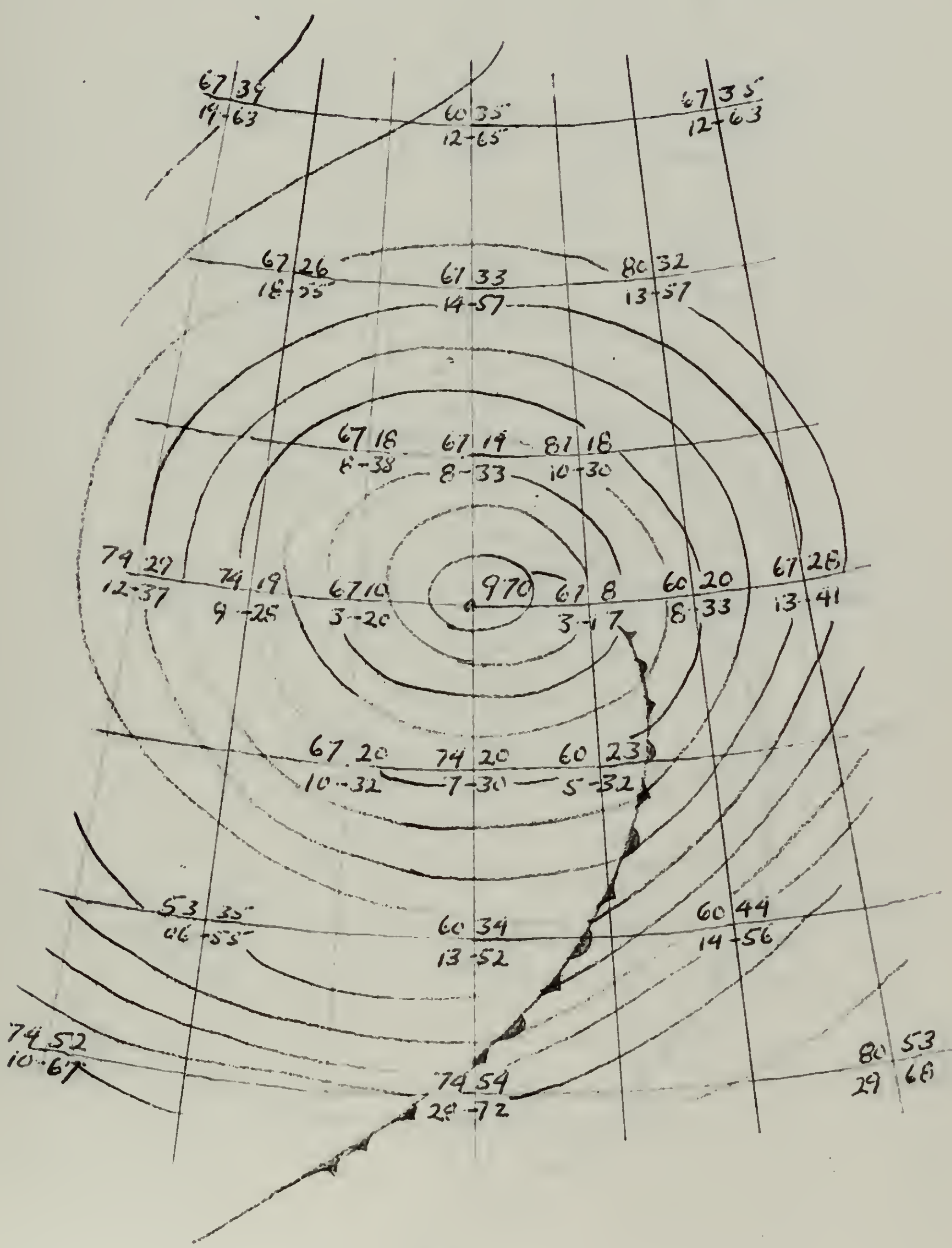


Figure 17-e: Type Z-1 Modal Cyclone Model for Fifth Day

(6)

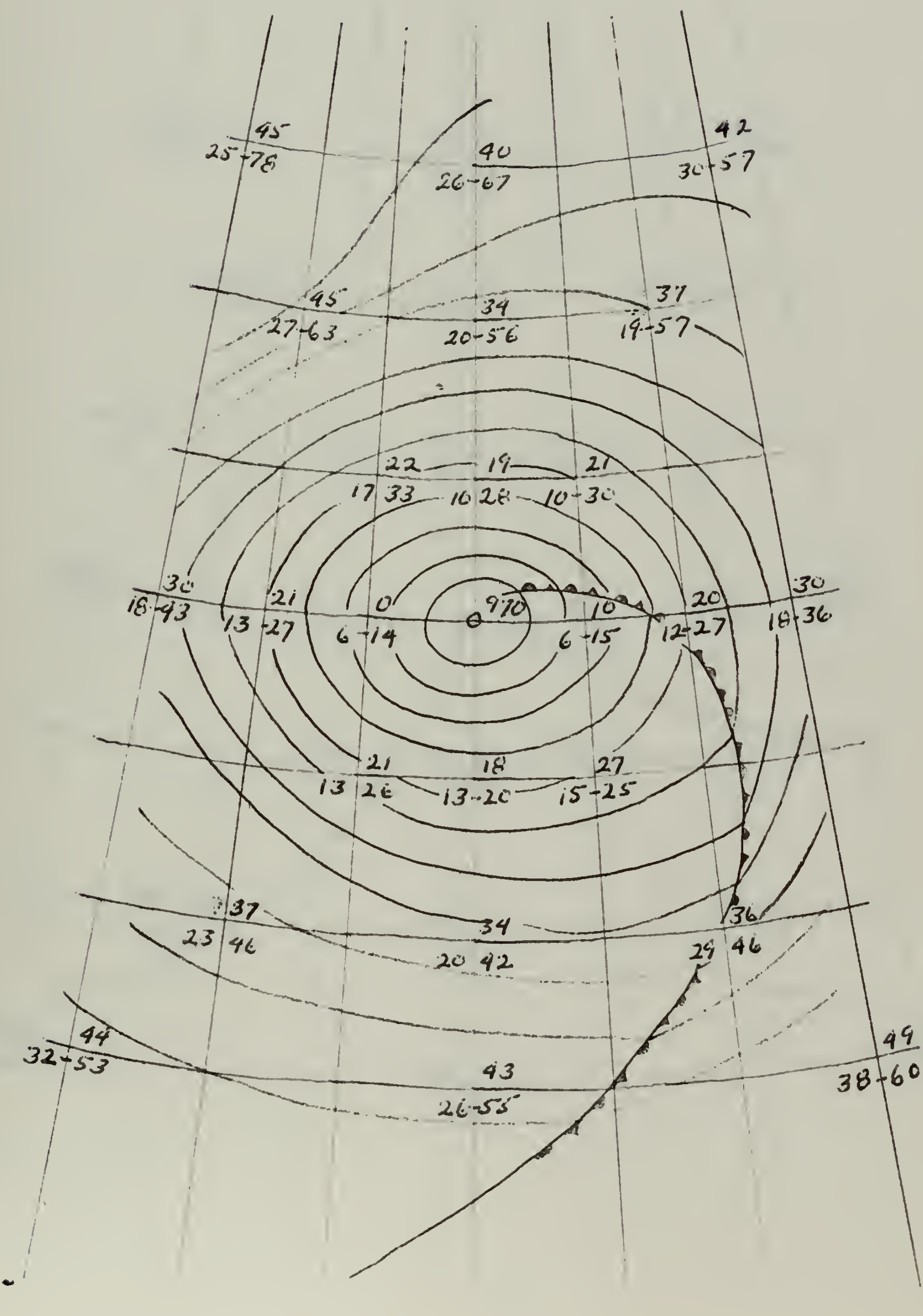


Figure 18-a: Type Z-4 Modal Cyclone Model for First Day

(11)

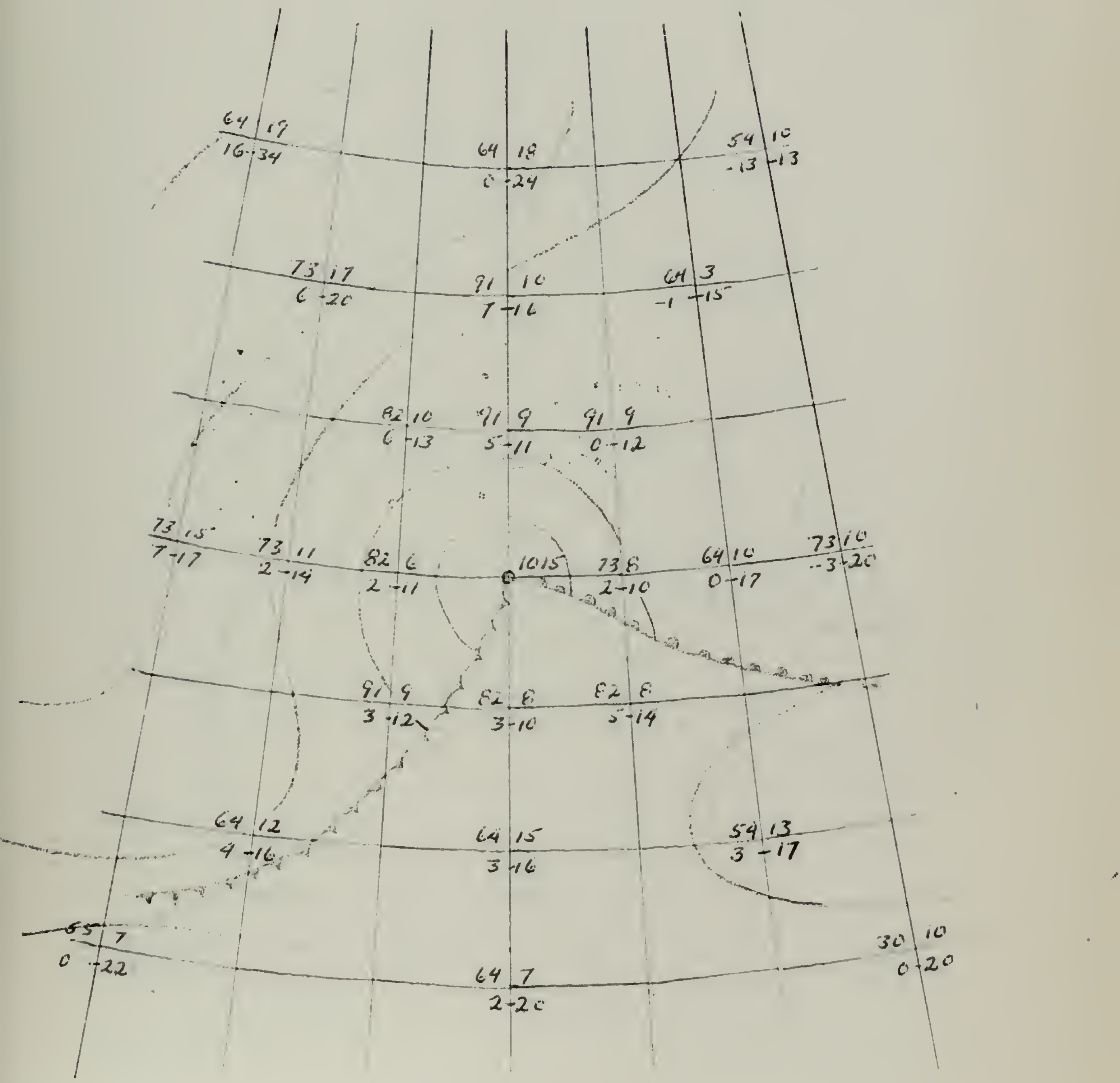


Figure 18-b: Type Z-4 Modal Cyclone Model for 2nd Day

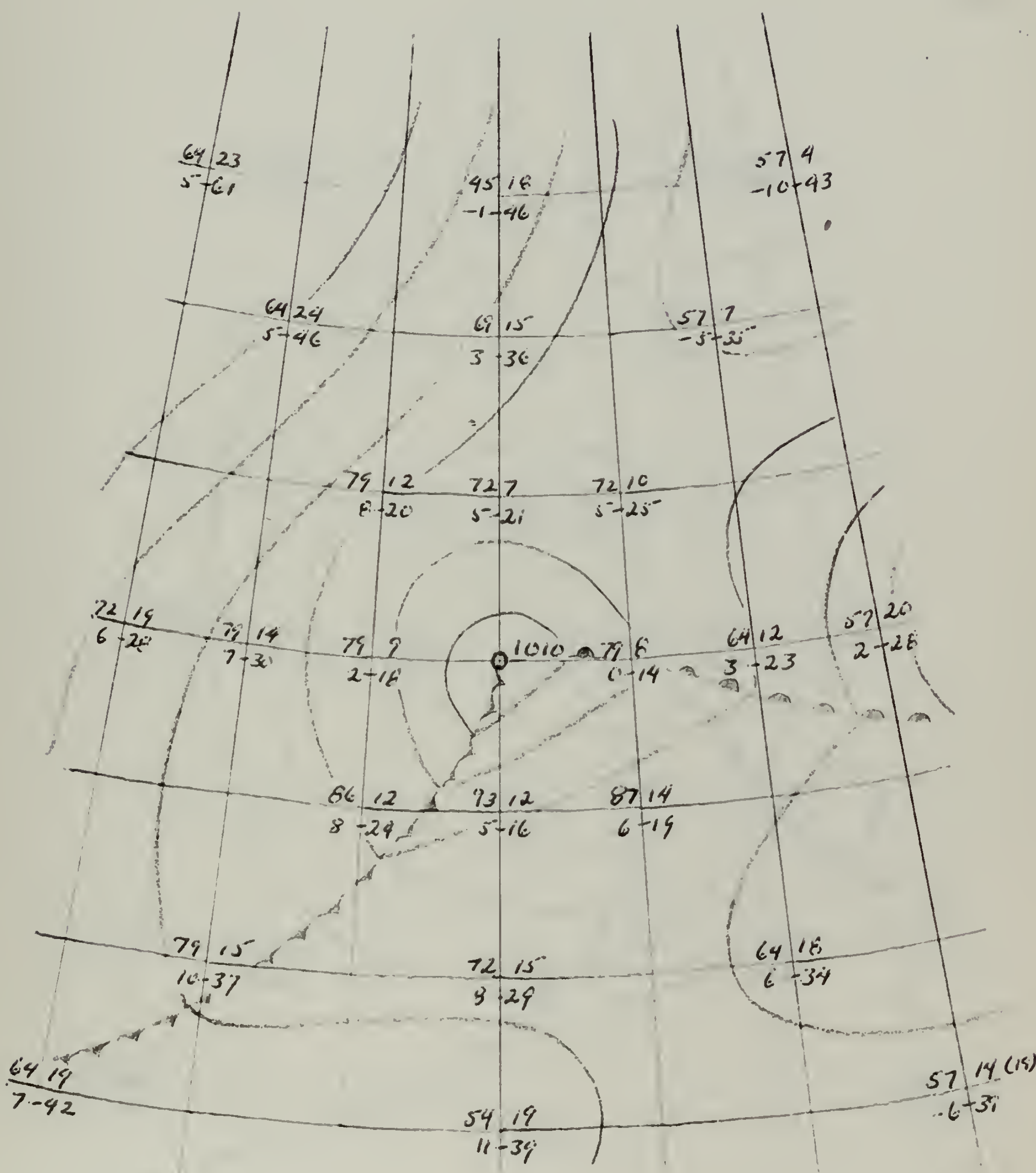
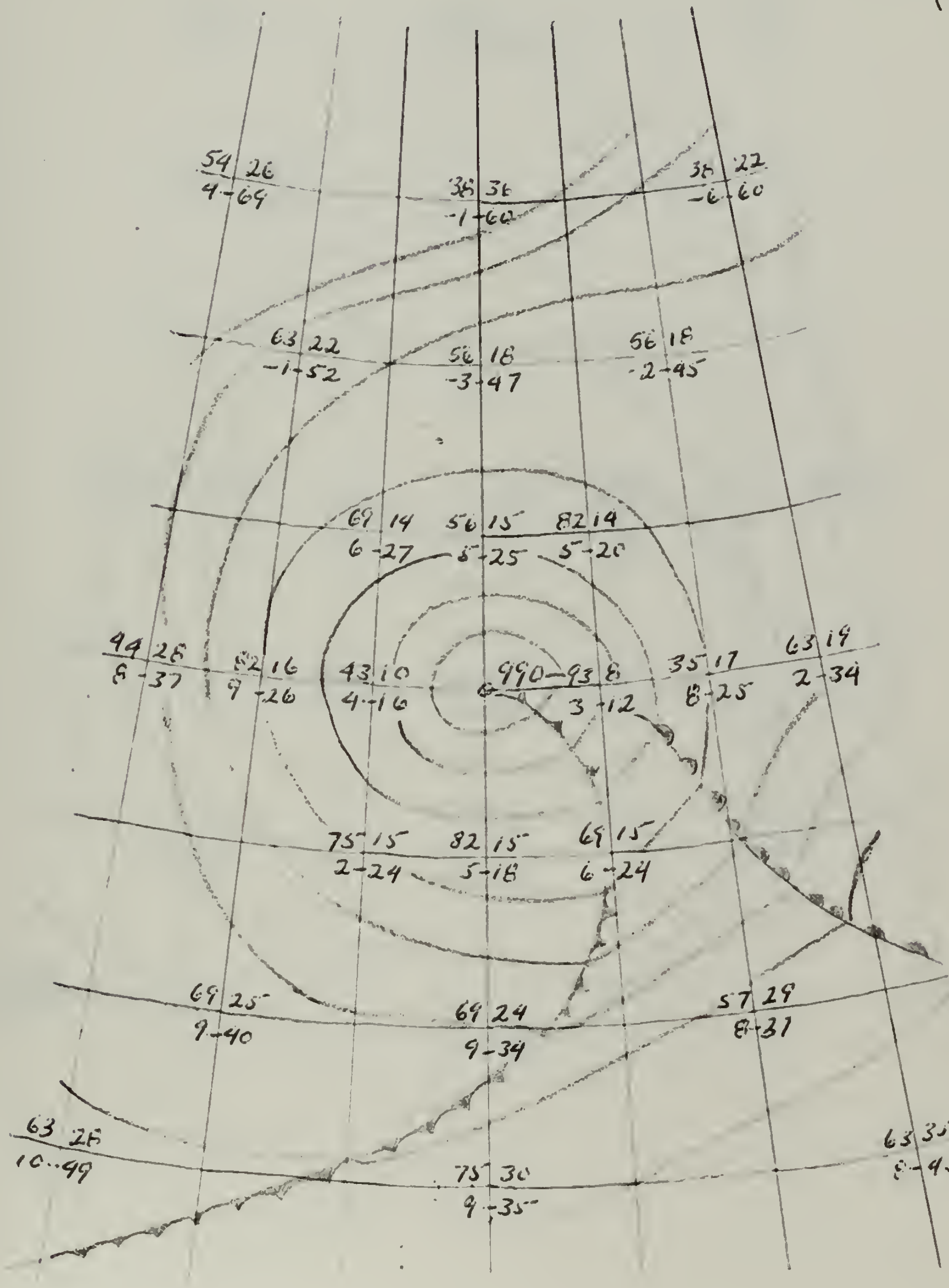


Figure 18-c: Type Z-4 Modal Cyclone Model for Third Day

(16)



[illegible]

[illegible]

Figure 18-d: Type Z-4 Modal Cyclone Models for Fourth Day

(15)

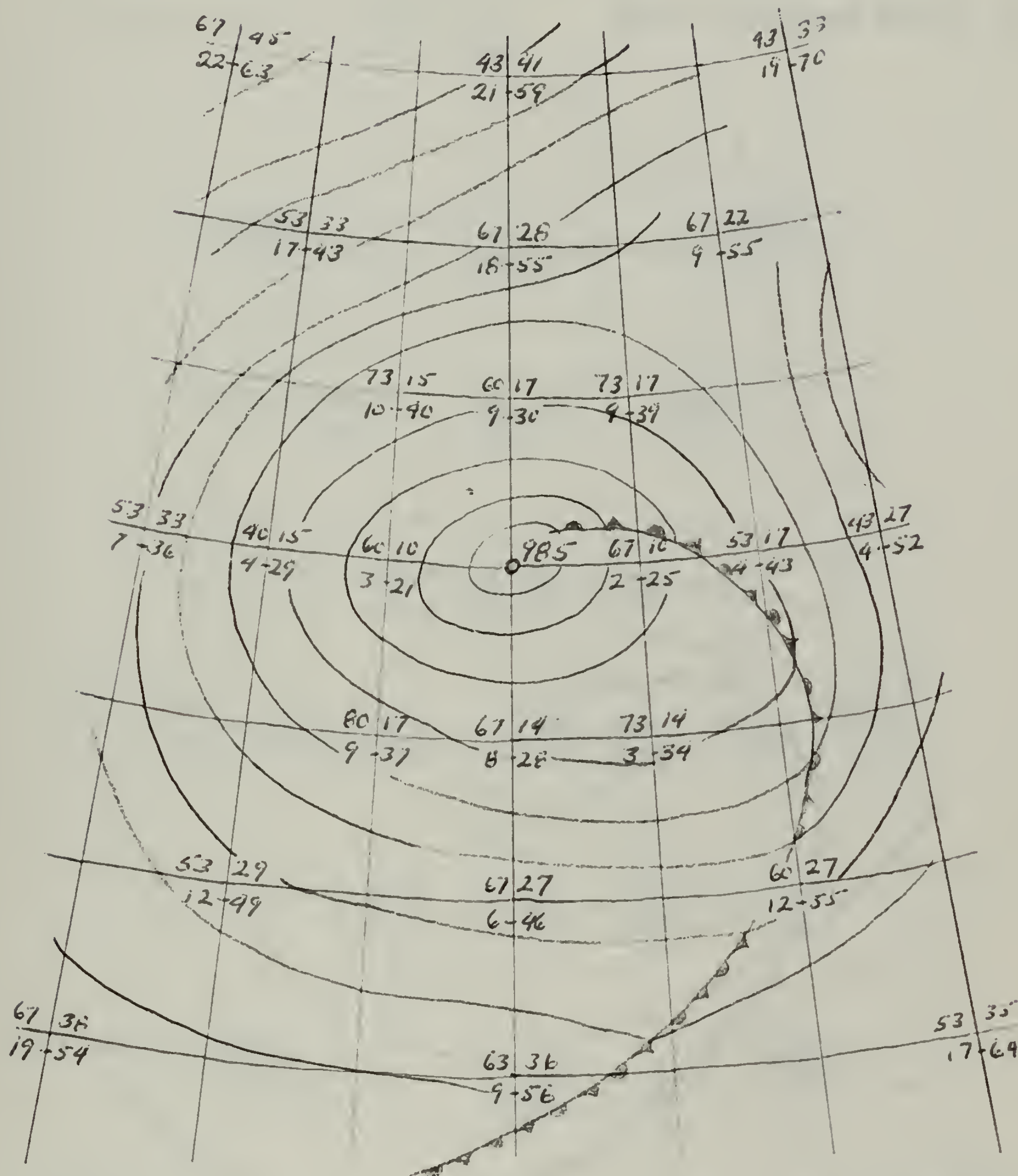


Figure 18-e: Type Z-4 Modal Cyclone Model for Fifth Day

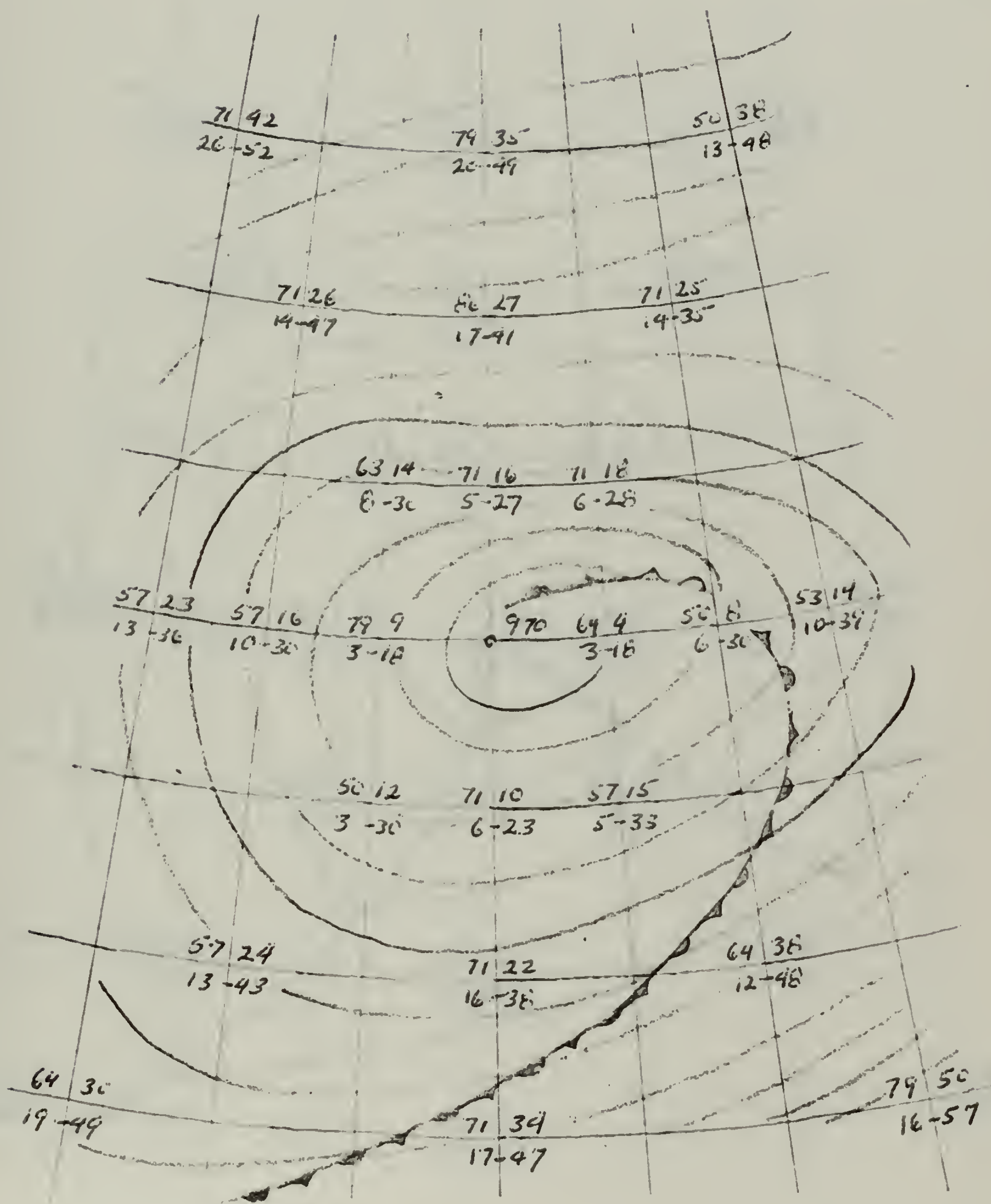


Figure 19-a: Type R-5 Modal Cyclone Model for First Day

(12)

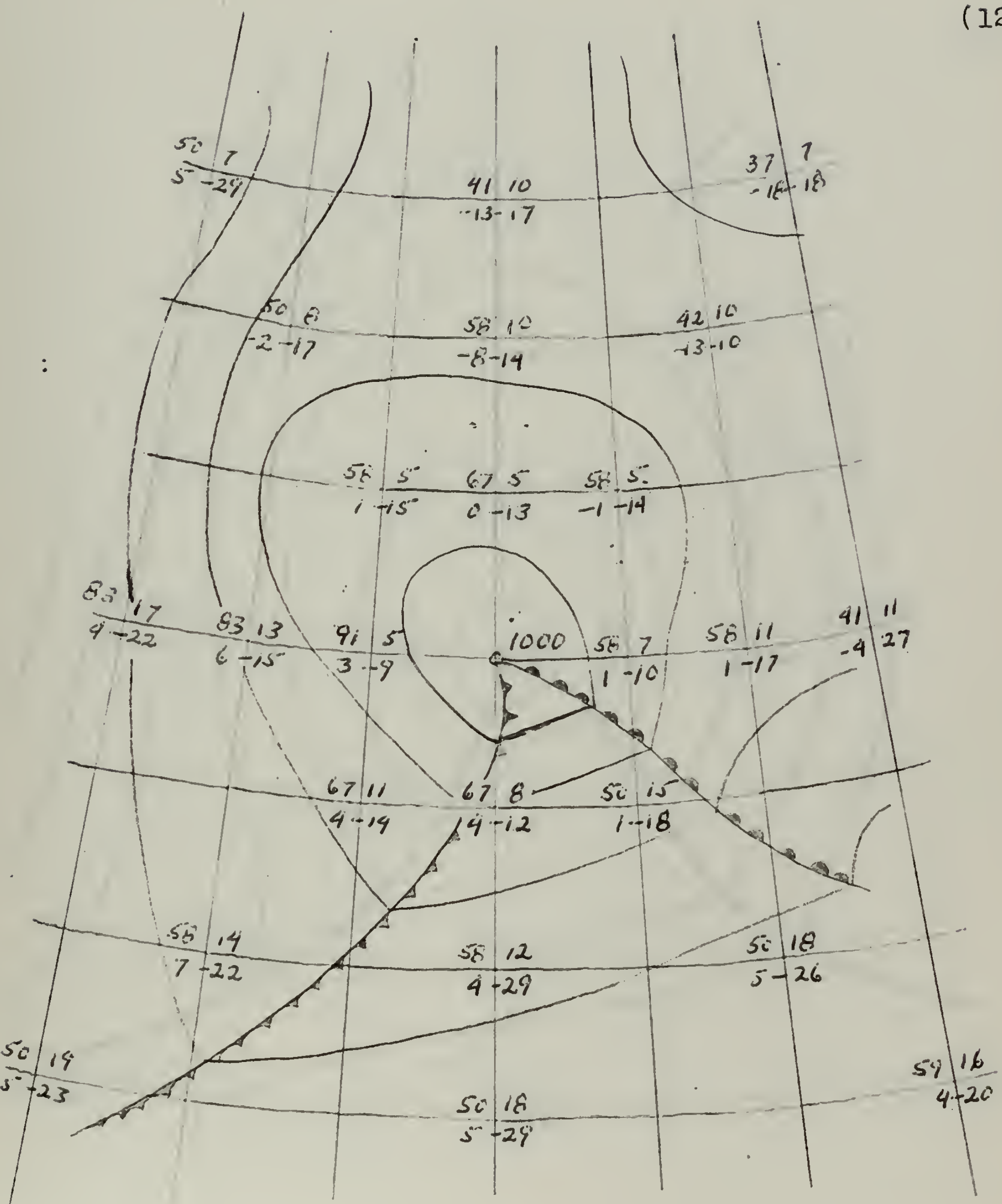


Figure 19-b: Type R-5 Modal Cyclone Model for Second Day

(16)

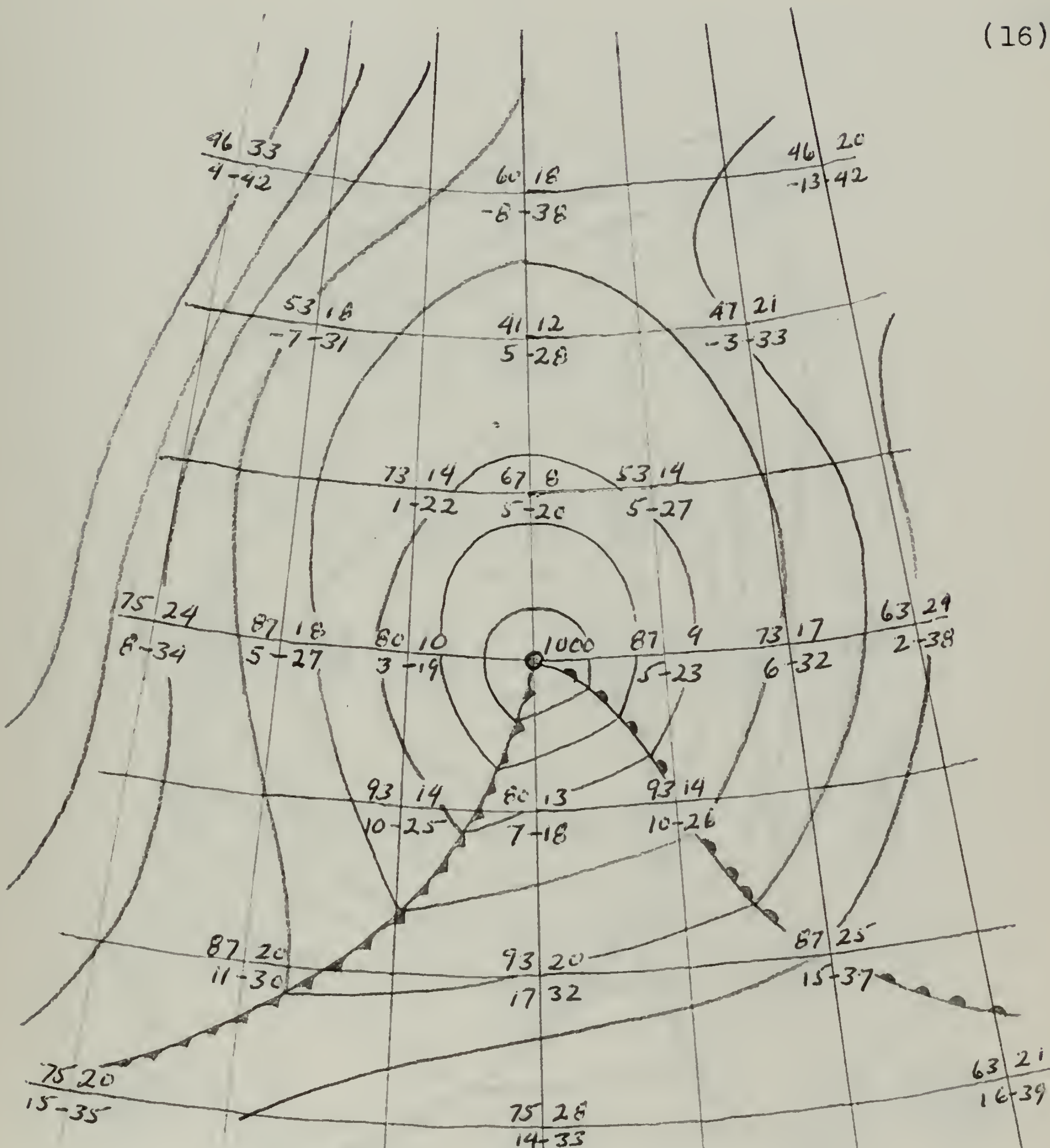


Figure 19-c: Type R-5 Modal Cyclone Model for Third Day

(13)

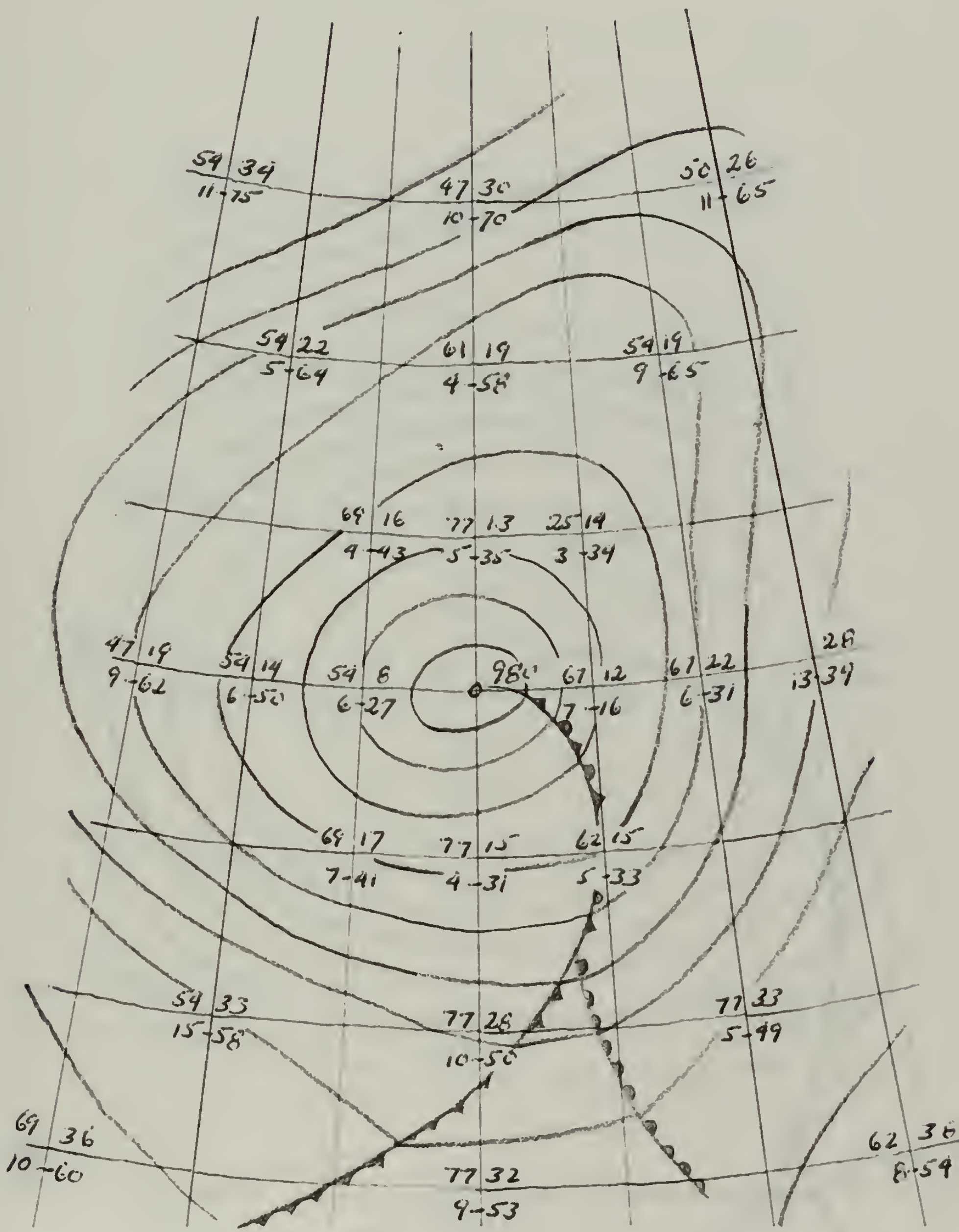


Figure 19-d: Type R-5 Modal Cyclone Model for Fourth Day

(10)

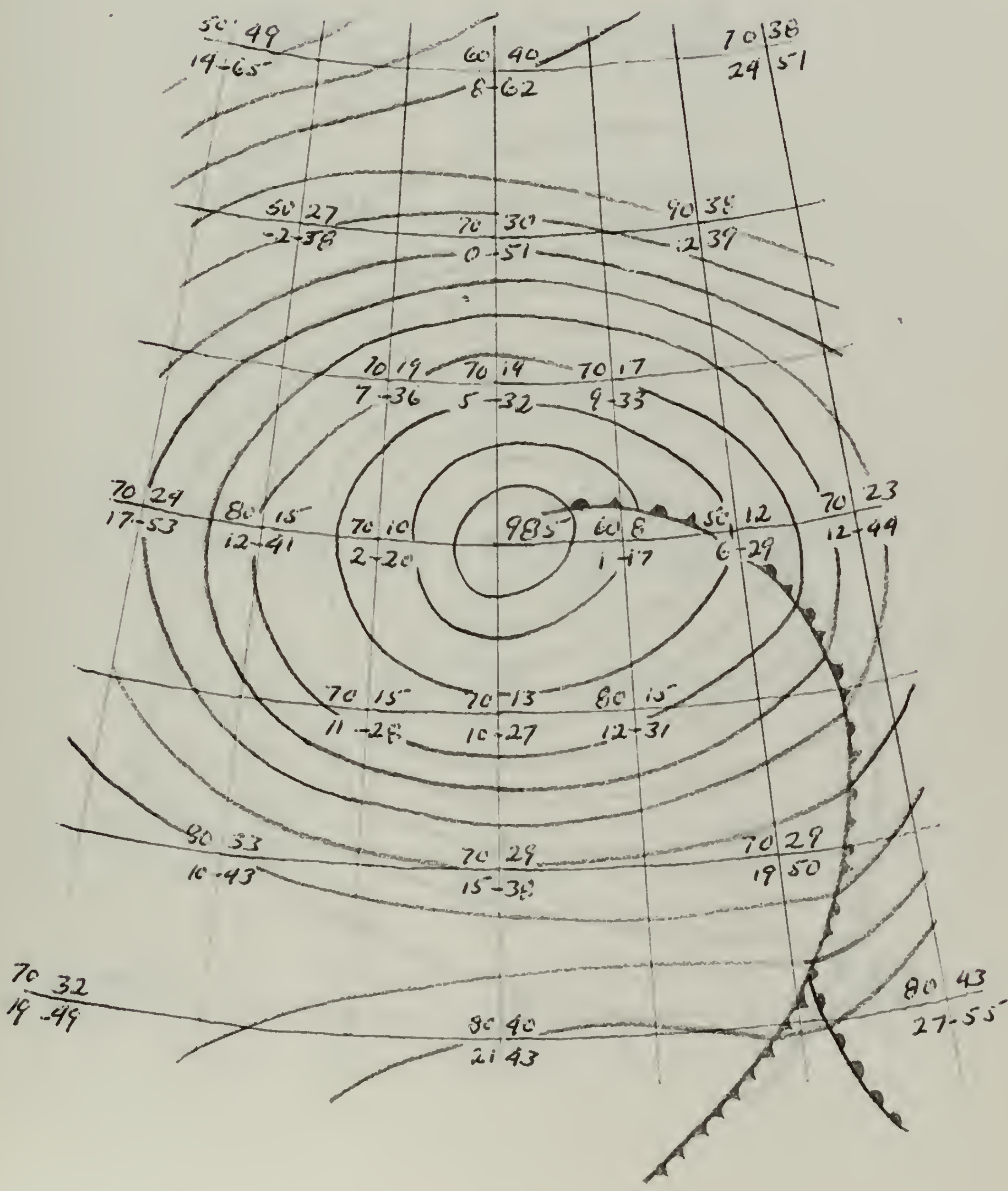


Figure 19-e: Type R-5 Modal Cyclone Model for Fifth Day

(5)

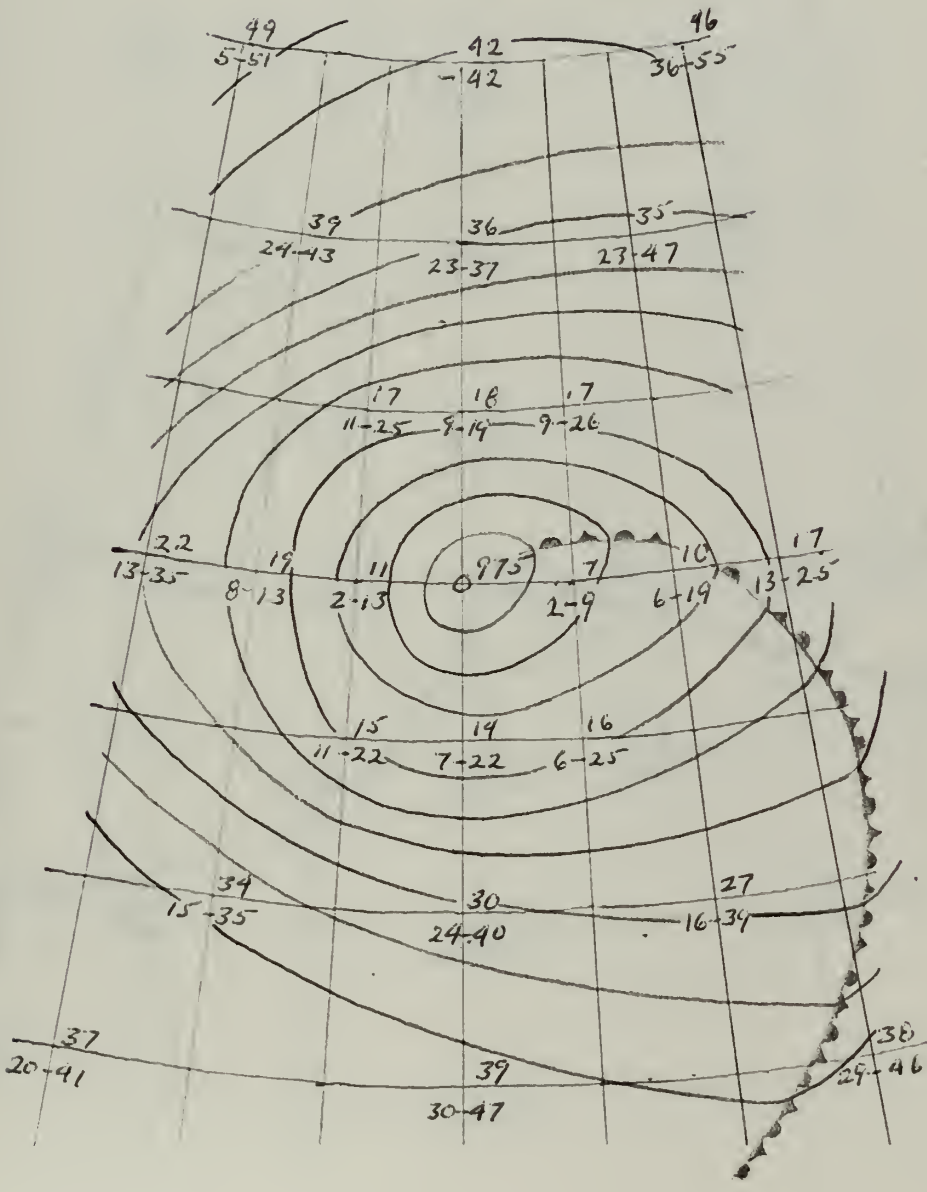


Figure 20-a: Type R-6 Medal Cyclone Model for First Day

(7)

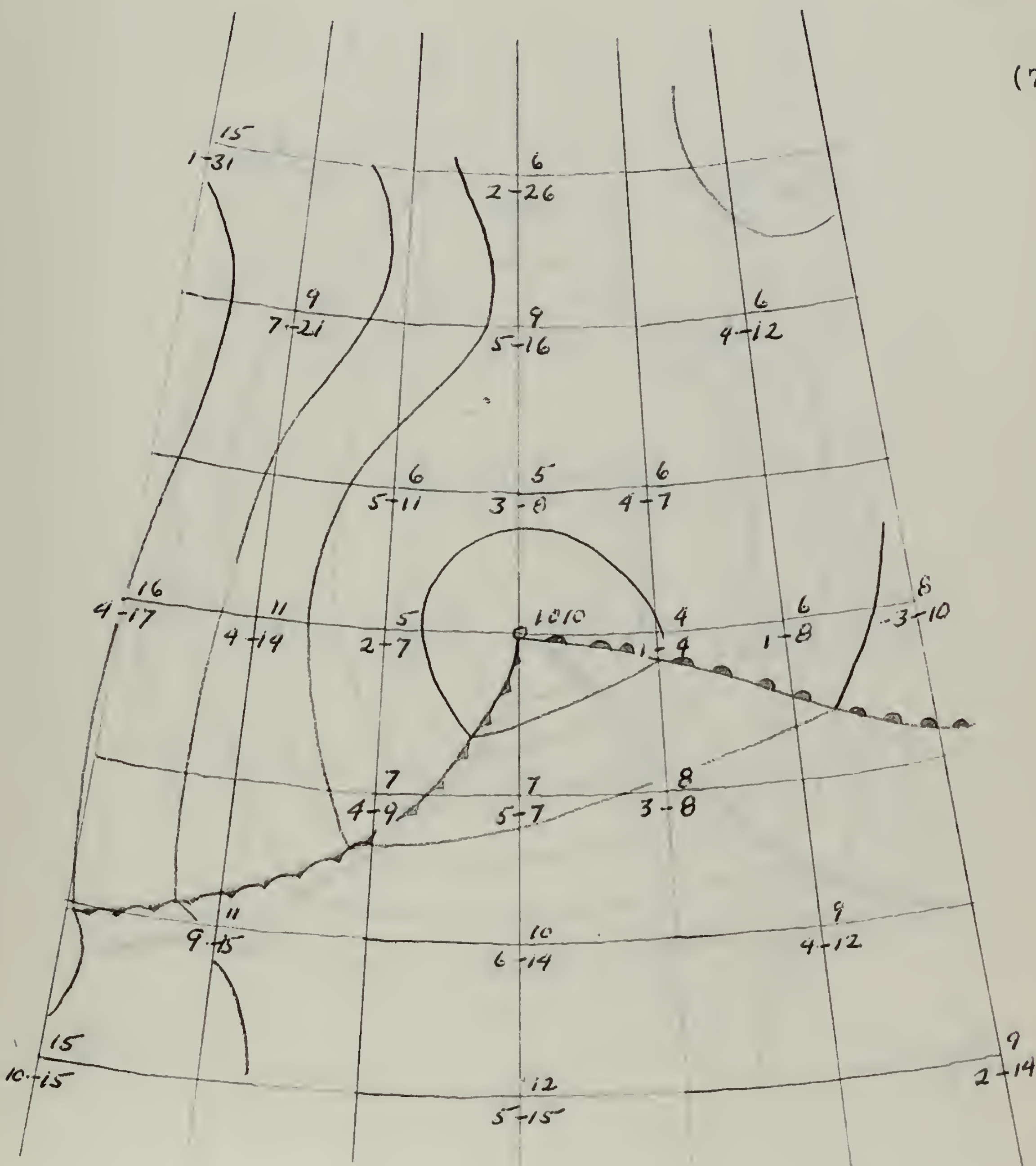


Figure 20-b: Type R-6 Modal Cyclone Model for Second Day

(8)

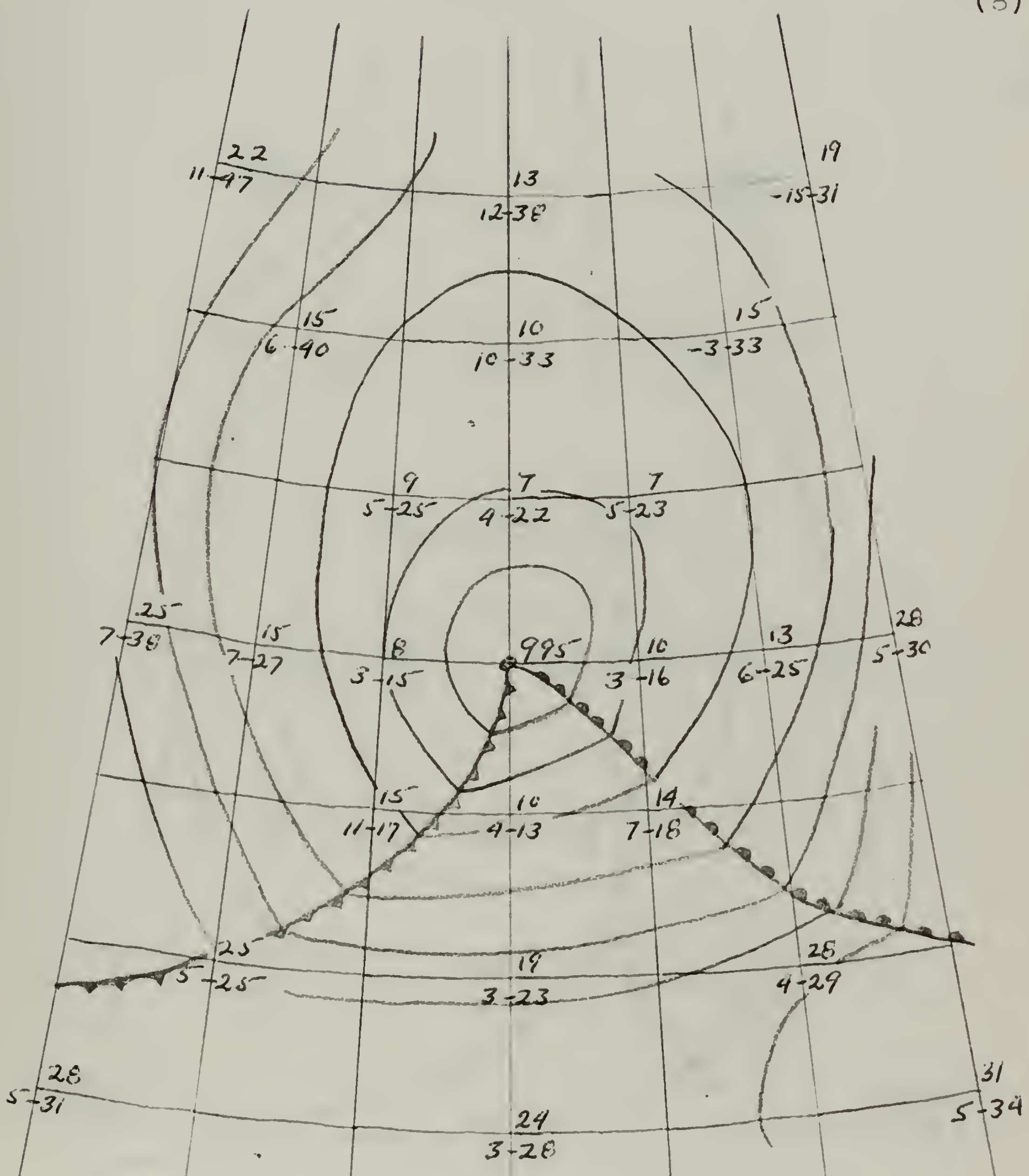


Figure 20-c: Type R-6 Modal Cyclone Model for
Third Day

(10)

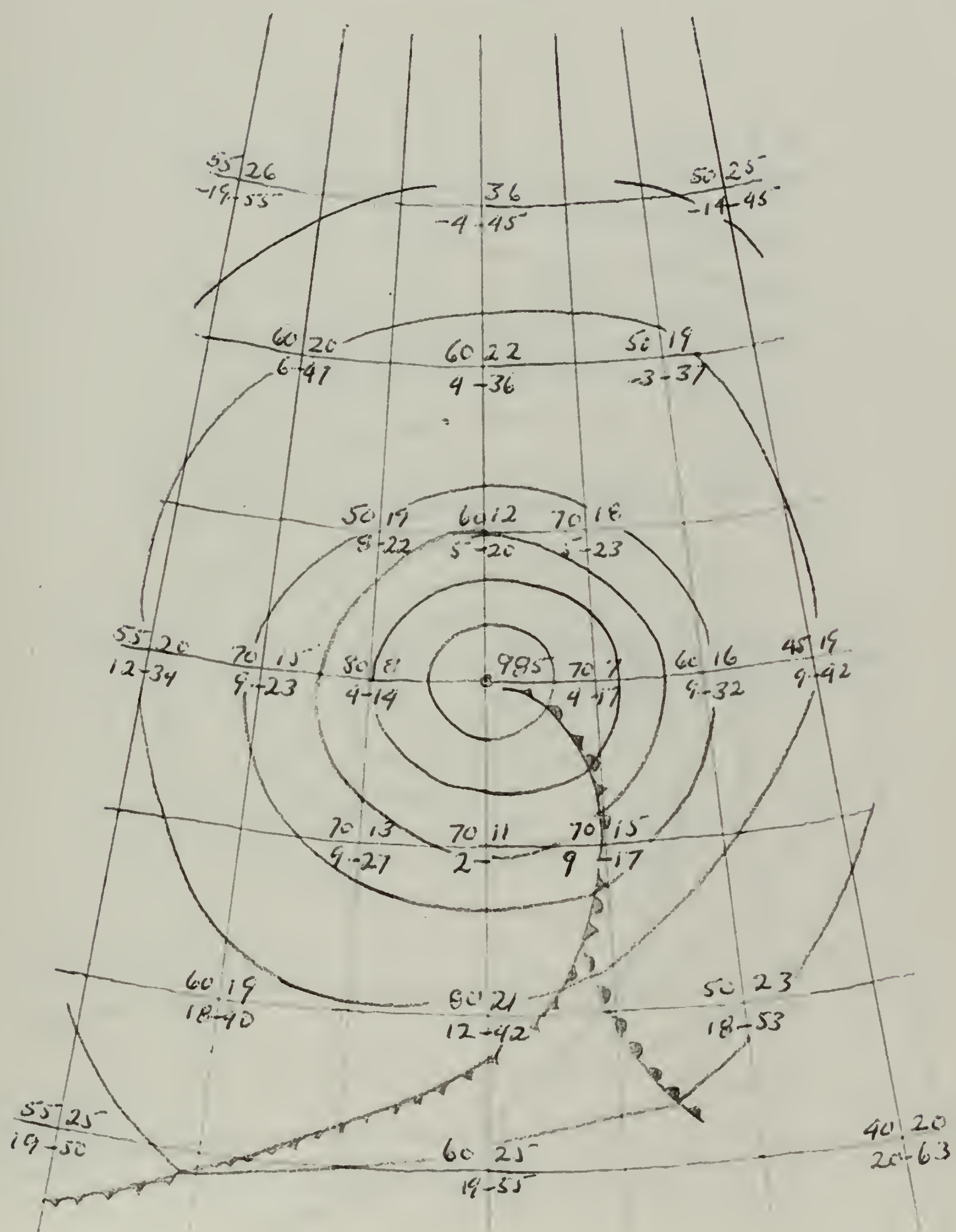


Figure 20-d: Type R-6 Model Cyclone Model for Fourth Day

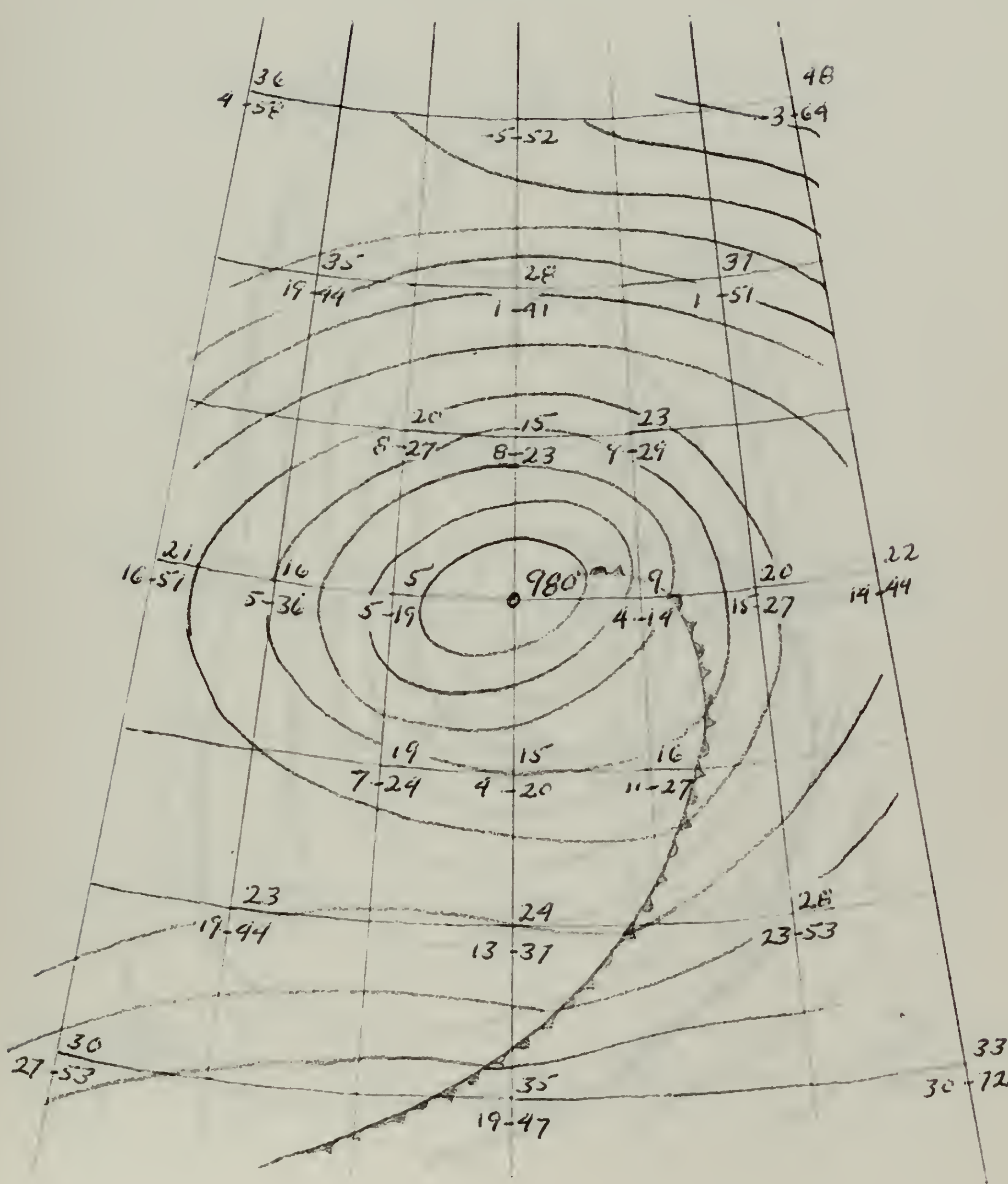


Figure 20-e: Type R-6 Modal Cyclone Model for Fifth Day

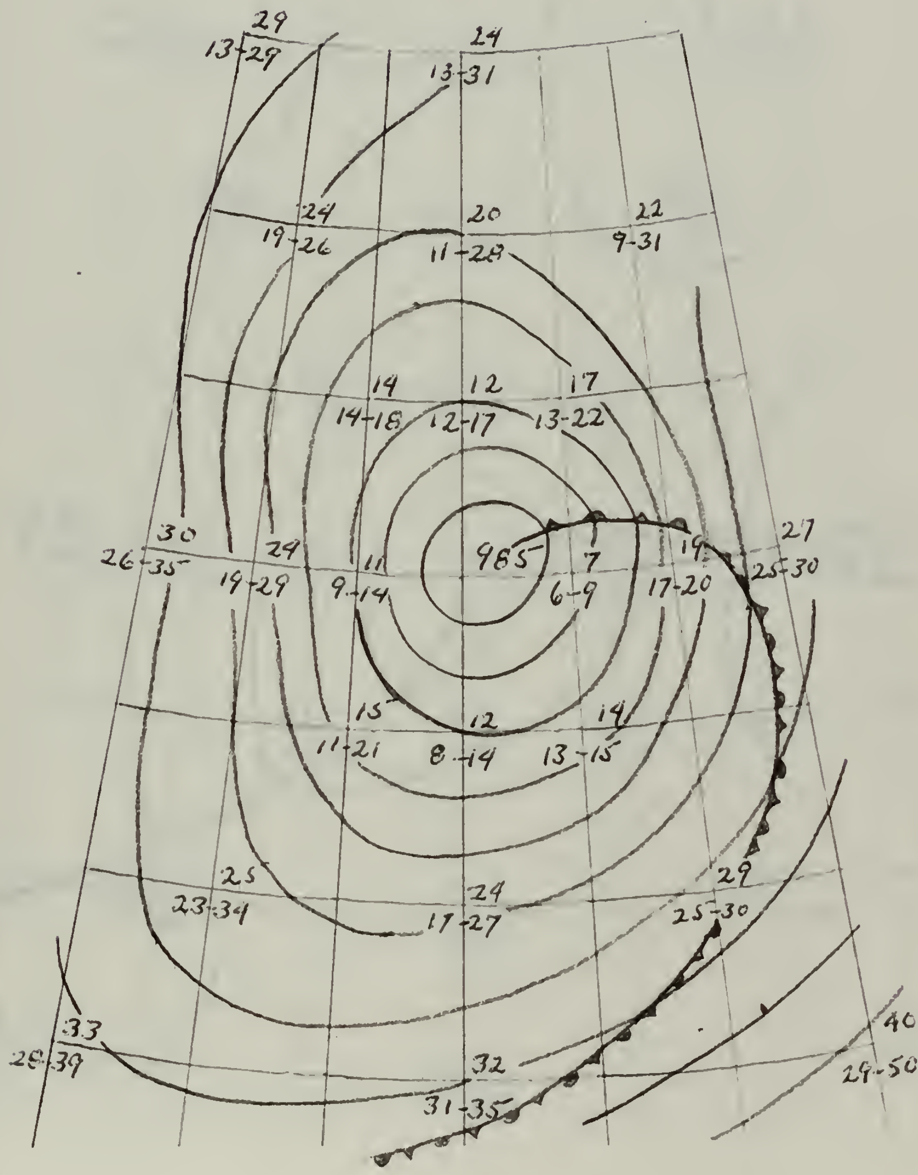


Figure 21-a: Type B-2 Modal Cyclone Model
for First Day

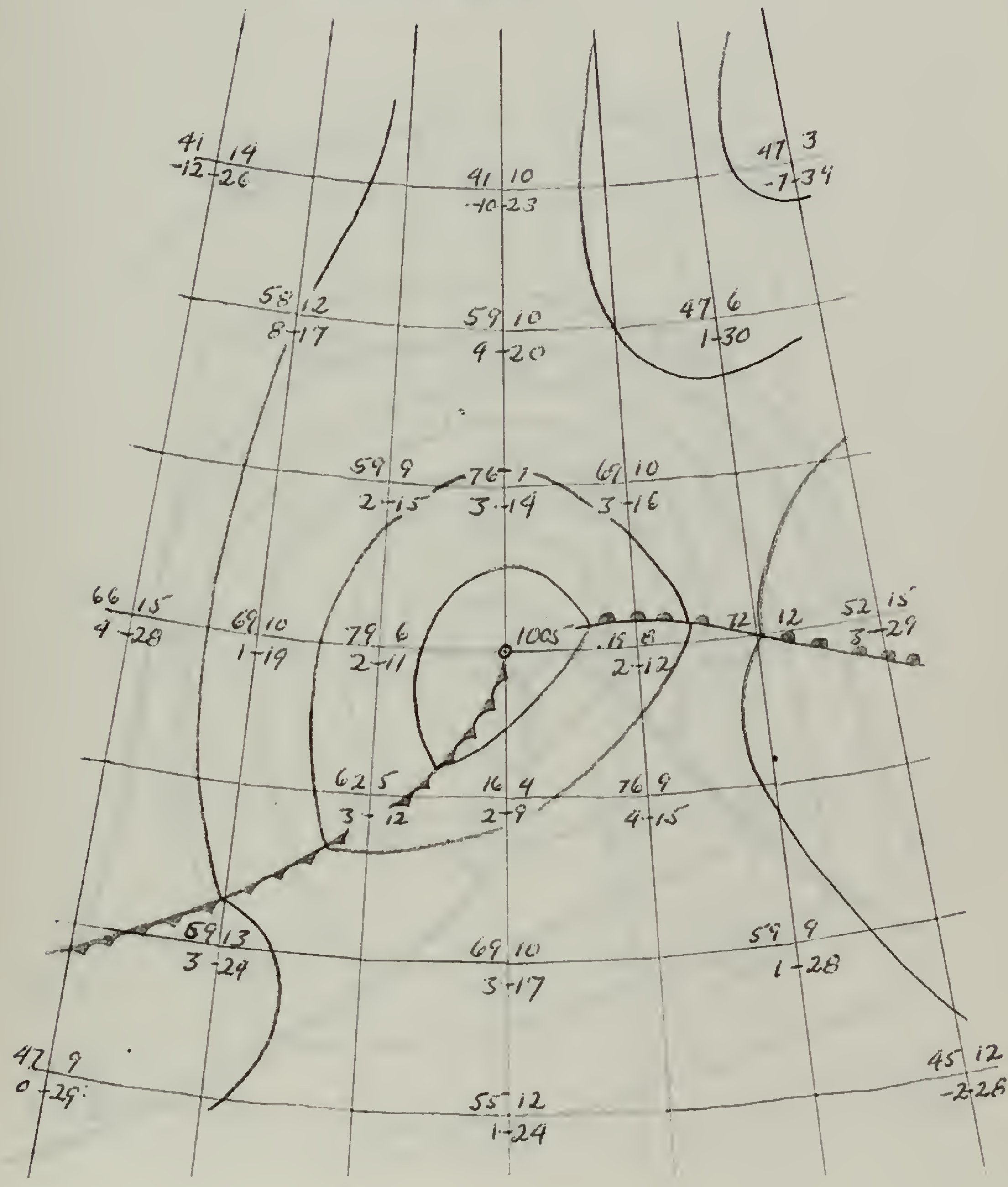


Figure 21-b: Type B-2 Modal Cyclone Model for Second Day

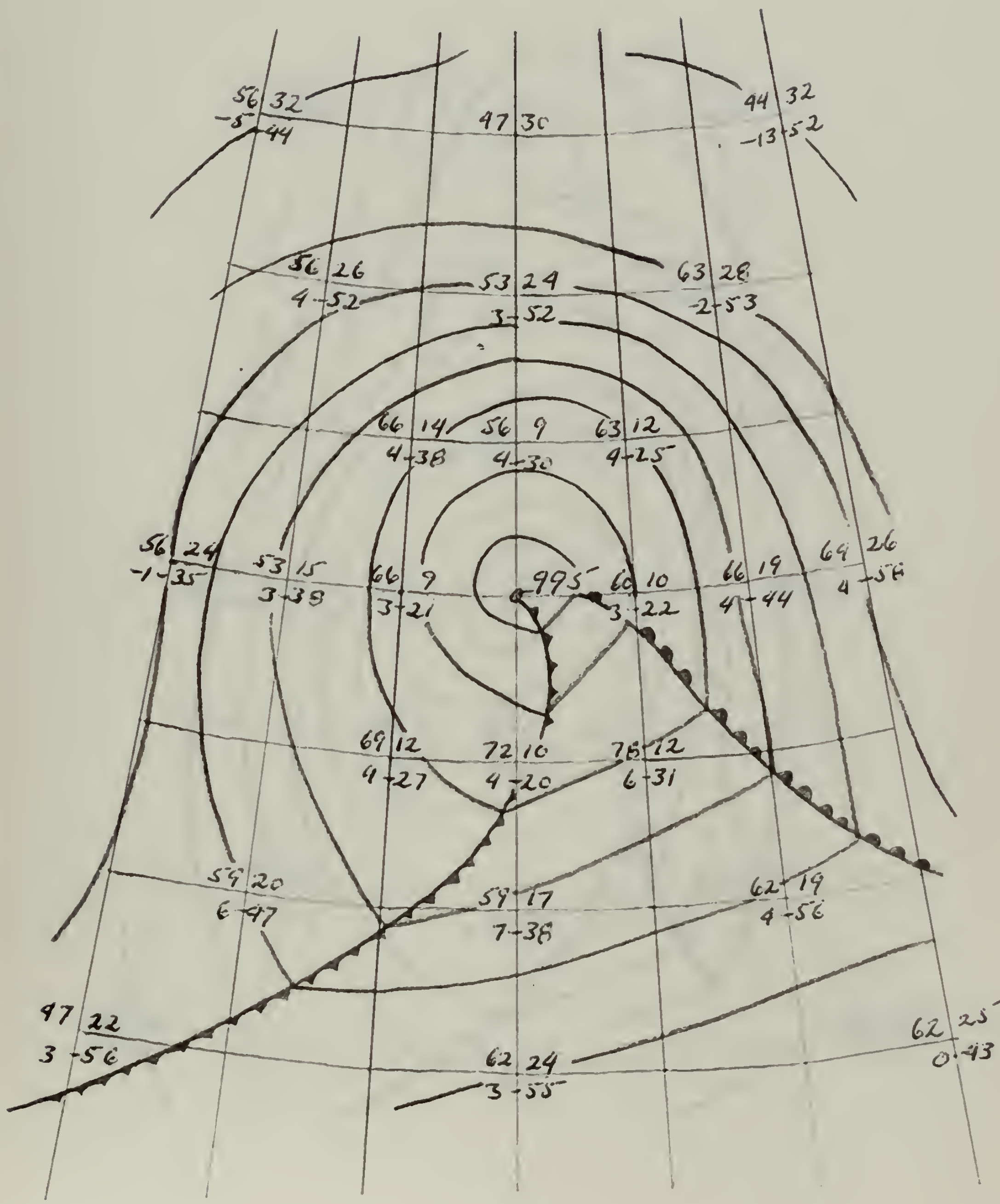


Figure 21-c: Type B-2 Modal Cyclone Model for Third Day

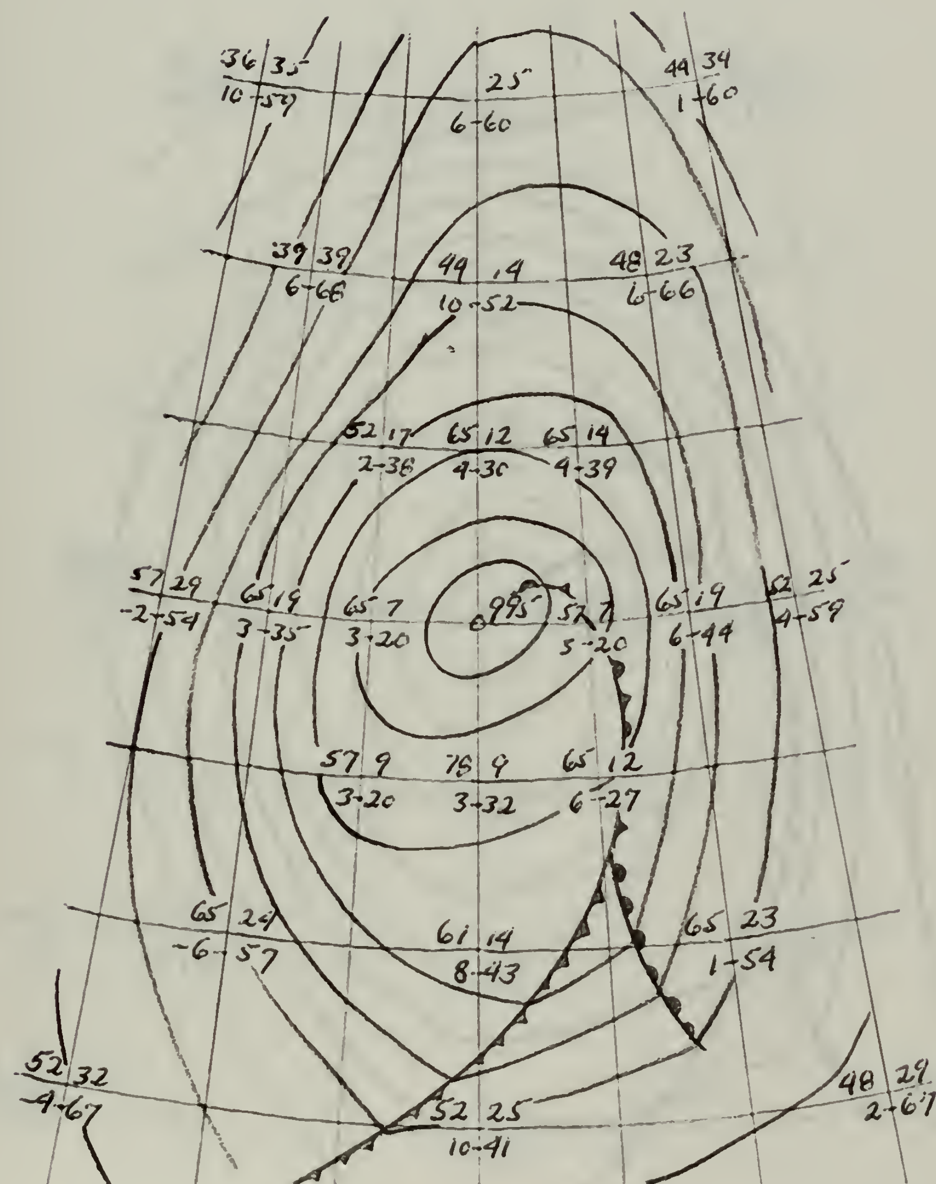


Figure 21-d: Type B-2 Modal Cyclone Model for Fourth Day

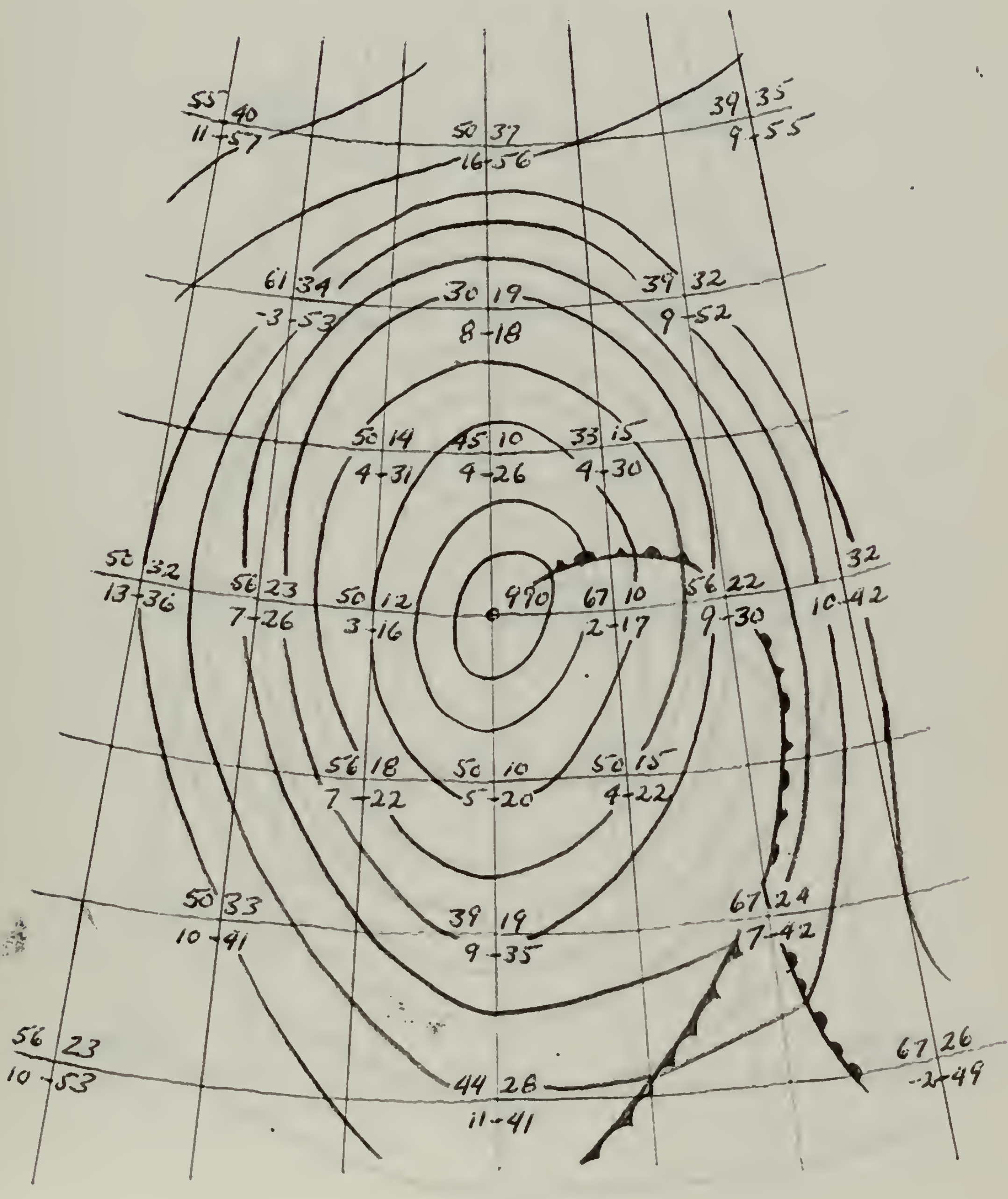


Figure 21-e: Type B-2 Type Modal Cyclone for Fifth Day

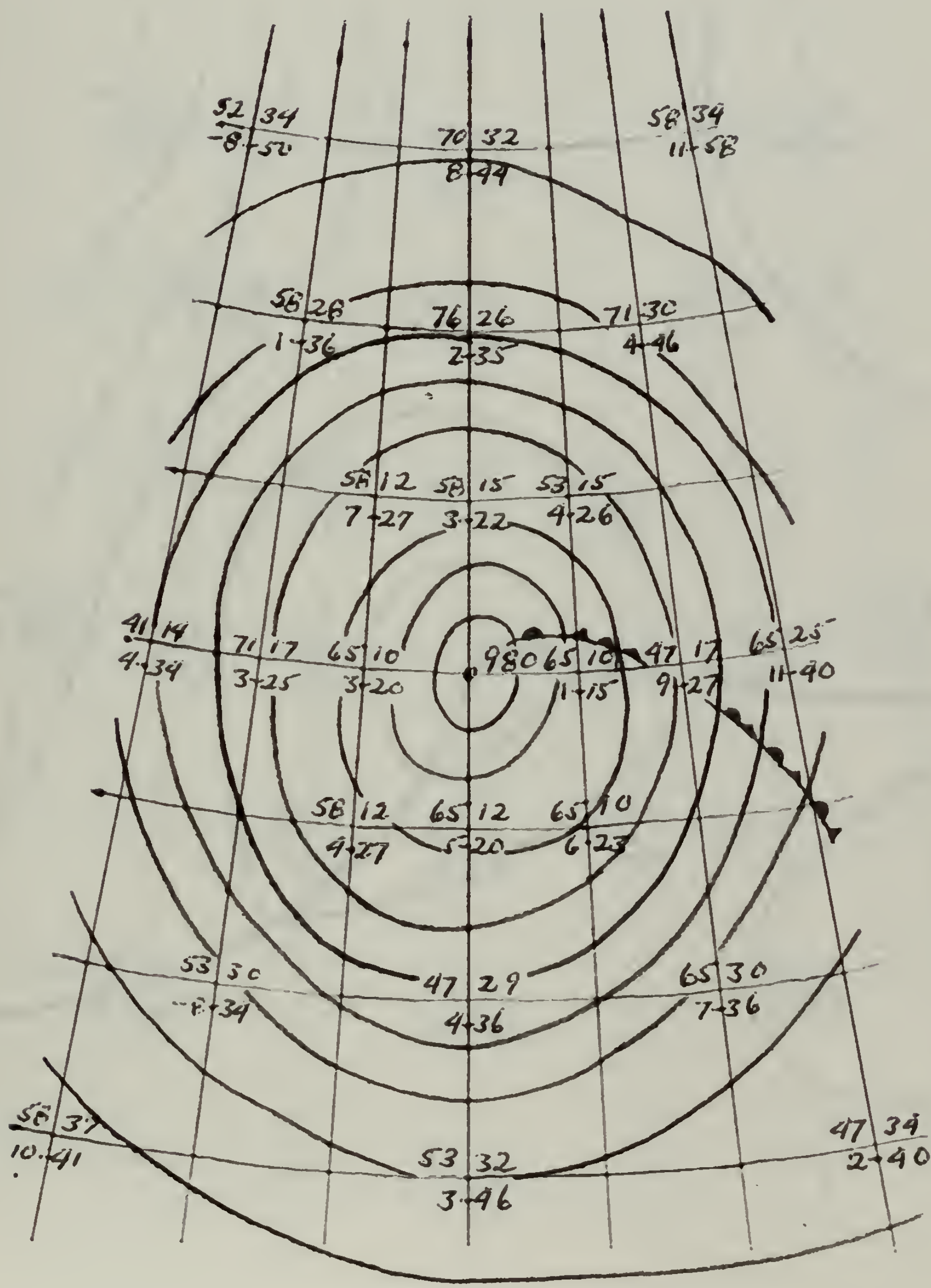


Figure 22-a: Type B-4 Modal Cyclone Model for First Day

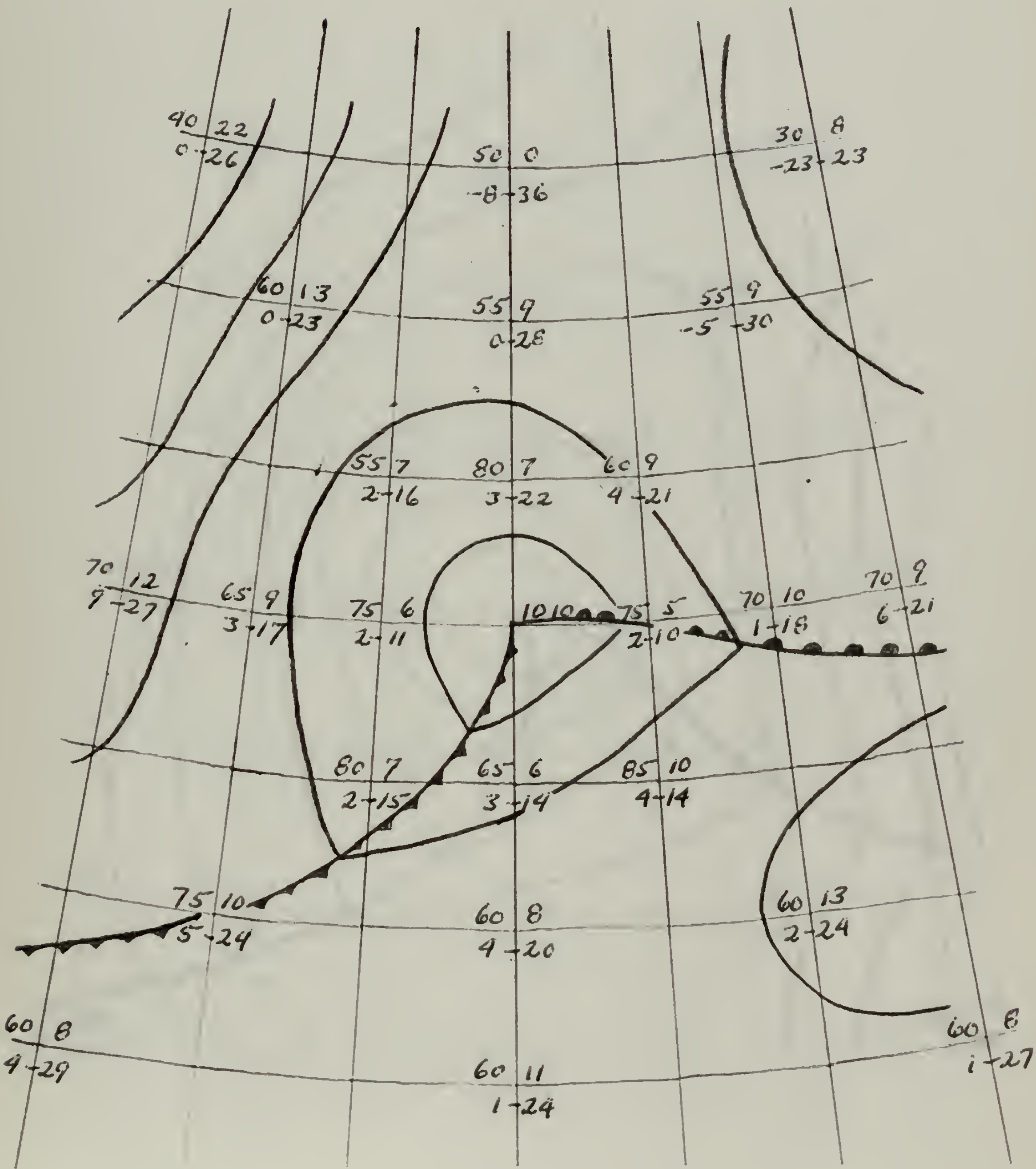


Figure 22-b: Type B-4 Modal Cyclone Model for Second Day

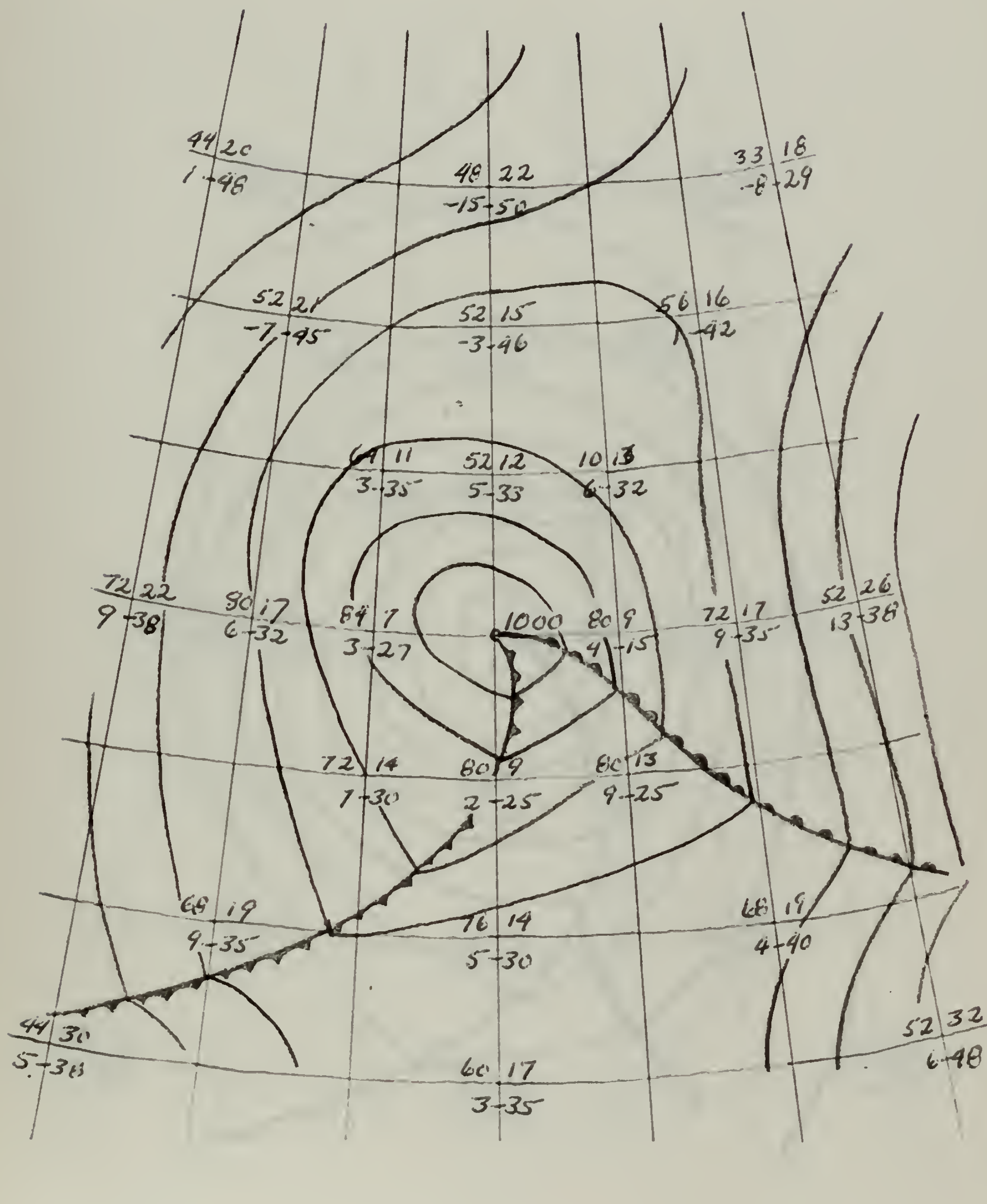


Figure 22-c: Type B-4 Modal Cyclone Model for Third Day

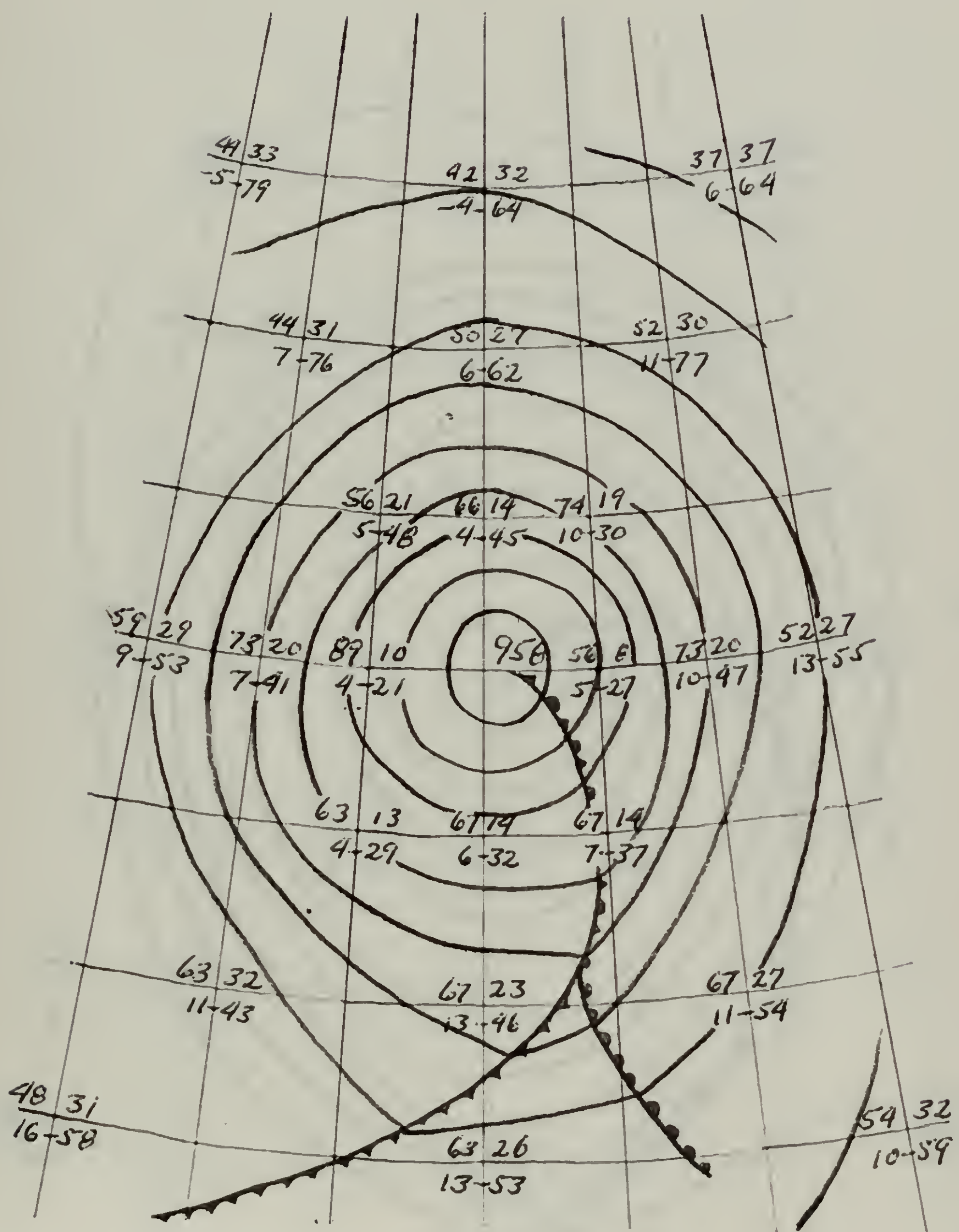


Figure 22-d: Type B-4 Modal Cyclone Model for Fourth Day

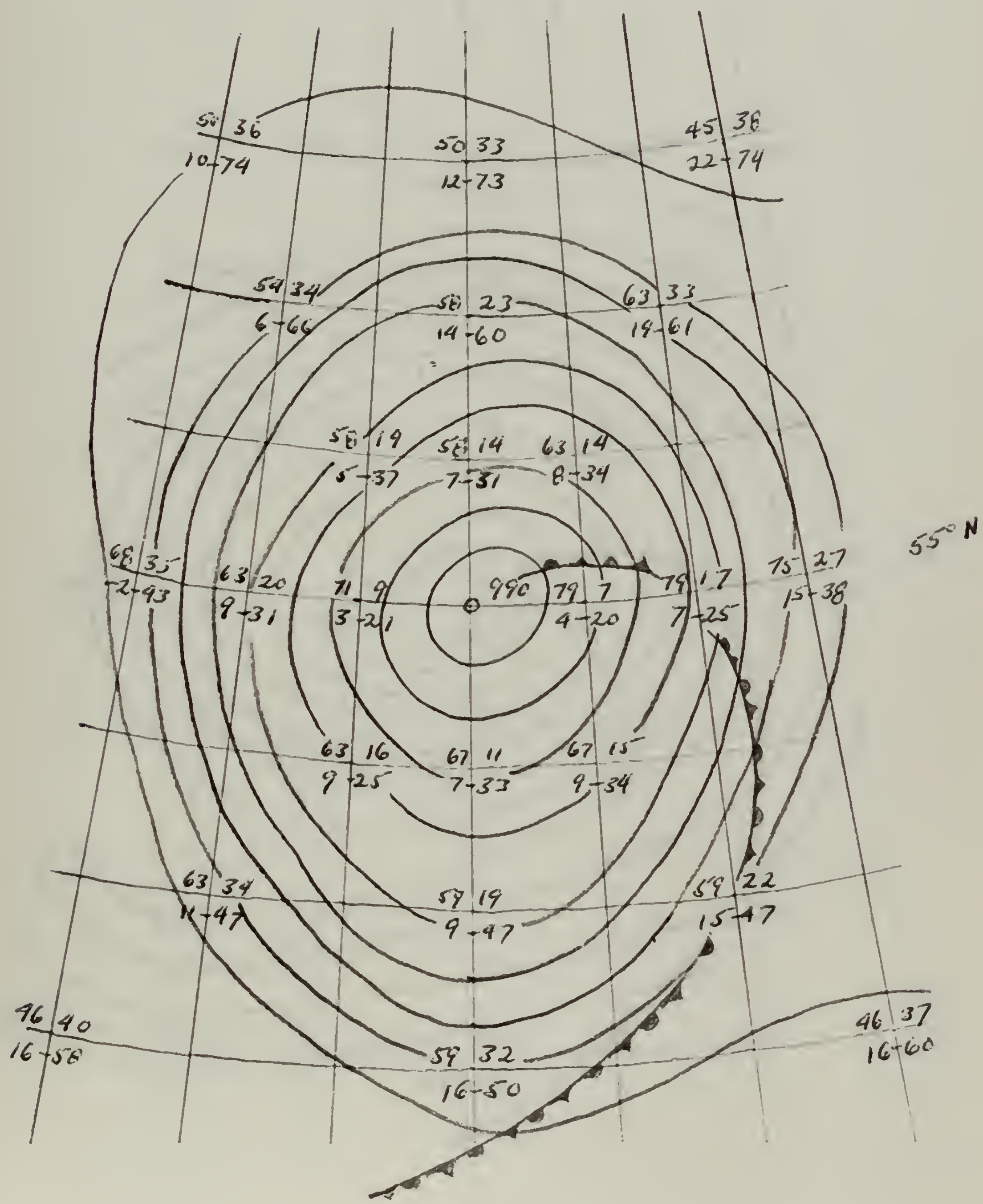


Figure 22-e: Type B-4 Modal Cyclone Model for Fifth Day